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SURVEY OF FIVE UTILITY BOILERS FOR RADIONUCLIDE EMISSIONS

Final Report

December 1983

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This report presents the results of an in-depth sampling program for radionuclides conducted by GCA in mid-1981 at ten coal-fired electric utility generating stations. This program assisted EPA's Office of Radiation Programs (ORP) in developing standards for radionuclides following their listing as hazardous air pullutants under Section 112 of the Clean Air Act (FR 44), p. 76738, November 8, 1979).[1]

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SECTION 1

SUMMARY

This report presents the results of an in-depth sampling program for radionuclides conducted by GCA in mid-1981 at ten coal-fired electric utility generating stations. This program assisted EPA's Office of Radiation Programs (ORP) in developing standards for radionuclides following their listing as hazardous air pollutants under Section 112 of the Clean Air Act (FR 44, p. 76738, November 8, 1979).[1]

Extensive sampling of flue gas emissions and other waste and process streams was performed at five coal-fired power plants. These plants represented the following variables:

- large and small units (56 to 874 MW),
- pulverized coal, traveling grate stoker, and cyclone furnace designs,
- subbituminous and lignite coal, and
- a variety of particulate control devices including mechanical collectors, wet scrubbers, and electrostatic precipitators.

Abbreviated sampling programs were conducted at five additional facilities for comparative purposes. Grab samples of solid and liquid waste and process streams were collected but there was no testing of flue gas emissions. It is important to note that this sampling program was a research effort and procedures that would be followed in a compliance investigation were not always followed.

For those plants where extensive sampling was conducted, the concentrations of five radionuclides in the uranium decay series (uranium-238, thorium-230, radium-226, lead-210, and polonium-210) and thorium-232 were measured. Results are shown in Table 1. Percentage closures and enrichment factors were computed for each radionuclide at each facility as a function of both measured and calculated plant parameters. Closure is defined as the ratio of material detected in the various plant effluent streams to the amount measured in all input streams. In most cases, percent closures less than 100 percent were obtained implying that not all material was accounted for in the plant effluent (due to sampling or analytical errors) or that measured coal activities were too high. Enrichment factors refer to the ratio of the total radionuclide concentration in the stack fly ash stream to the radionuclide concentration in the coal ash. Values greater than unity indicate that the radionuclide is enriched in the fly ash emitted to atmosphere.

TABLE 1. SUMMARY OF RADIONUCLIDE EMISSIONS TO AIR FROM FIVE COAL-FIRED ELECTRIC GENERATING STATIONS

	Coal			Stack fly ash		Estimated annual radionuclide stack emission rate, mCi/yr[a] (percent of total radionuclide input from coal)					
Station	Feed rate, (short ton/hr)	Ash content (percent)	Estimated particulate removal efficiency (percent)	Emission rate (g/hr)	Percent of emissions <1 μm (percent)	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
M-1	340	24.2	97.99	5.6×10^5	79	120 (2.9)	63 (1.5)	1000 (24)	340 (8.3)	17 (0.5)	8.5 (1.8)
M-15	34	9.1	99.5	7.2×10^3	27	2.3 (6.5)	0.5 (1.3)	0.6 (1.6)	NC -	0.3 (1.0)	0.1 (0.4)
M-33	433	15.1	97.16	5.7×10^5	2	14 (0.5)	13 (0.5)	22 (0.9)	30 (1.2)	12 (0.5)	8 (0.5)
M-34	646	23.1	99.97	2.8×10^4	15	1.3 (<0.1)	2.9 (<0.1)	2.9 (<0.1)	24 (0.4)	1.2 (<0.1)	1.1 (<0.1)
M-99	49	9.0	98.75	2.0×10^4	17	0.06 (<0.1)	0.1 (0.2)	2.8 (1.5)	NC -	0.06 (<0.1)	0.06 (<0.1)

[a] Calculated by assuming the plant operates 5,694 hr/yr (65 percent load factor).

NC - Not Counted.

Most of the radionuclides enter each plant in the coal except for Site M-1 (which employed a limestone scrubber for SO_x control) where limestone accounted for about 10 percent of total radionuclide input. In general, the largest amounts of radionuclides detected in the plant effluent were found in the hopper ash from the first particulate collector after the boiler.

Emissions of the various radionuclides were generally quite small and with few exceptions were less than 3 percent of total input from coal. The most notable exception was stack emissions of polonium at Site M-1 which were 175 µCi/hr and represented 24 percent of total polonium input from the coal. The only other exceptions were lead emissions at Site M-1 (60 µCi/hr and 8.3 percent of total input) and uranium emissions at Site M-15 (0.4 µCi/hr and 6.5 percent of total input). For all six radionuclides, stack emissions were highest for Site M-1 followed by Site M-33. These latter two sites also had the lowest overall particulate removal efficiencies of the five plants. Additional factors contributing to the relatively high emissions at Site M-1 were: highest coal activity for all measured radionuclides, highest ash content coal, and highest percent of stack particulate emissions less than 1 µm in diameter. Polonium and lead consistently showed the highest levels of atmospheric emissions and, thus, their calculated enrichment factors were much higher than those for the other four radionuclides. In general, however, enrichment factors were quite variable and highly site-specific.

There is firm evidence that only very small amounts of radionuclides, if any, are released to the air in the gaseous state. Results of specific sampling performed to test the hypothesis that some radionuclides, particularly polonium-210 and lead-210, might be in the gaseous state in stack gases released to the air, showed negligible gas phase radionuclide emissions.

Radionuclide stack emissions were associated with the small particle fraction (<1 µm in diameter) in almost every case studied regardless of that fraction's percentage of the total fly ash collected. Uranium, polonium, and thorium-232 were most exemplary of this phenomenon.

The results can be judged on the basis of percent closures for each radionuclide. Low percent closures indicate sampling or analytical errors, inaccurate assumptions concerning plant parameters, or innaccurate measurements of radionuclide concentrations in coal. Closure is sensitive to errors in the radionuclide analyses of coal samples since coal accounts for essentially all of the radionuclide input at each plant. Coal analyses for two of the sites (M-15 and M-99) were quite variable and thus the results for these plants are uncertain. In general, lead measurements were quite variable apparently because of the difficulty with the analytical chemical procedure.

Radionuclide emissions from those coal-fired power plants investigated for this report are low compared to radionuclide input to the plant within the coal and are dependent upon the type of coal and the overall particulate removal efficiency of the plant.

SECTION 2

INTRODUCTION

The Environmental Protection Agency listed radionuclides as a hazardous air pollutant on November 8, 1979 (44 FR 76738)[1] under the provisions of Section 112 of the Clean Air Act. In support of standards development, the Agency is assessing the public health impact of radionuclide emissions from a variety of emission source categories, including coal-fired power plants. Large emissions of radionuclides from coal-fired boilers are not expected because the amount of radionuclides potentially emitted is limited by the naturally occurring levels of uranium and thorium in the coal. To experimentally measure the amount of radionuclides emitted from coal-fired boilers and to determine how radionuclides move through the process streams of the typical coal-fired boiler, GCA conducted an extensive research emission testing program for EPA in 1981 at five coal-fired electric utility plants:

- La Cygne Station, La Cygne, Kansas (Site M-1)
- Lewis and Clark Station, Sidney, Montana (Site M-15)
- Big Brown Station, Fairfield, Texas (Site M-33)
- Monticello Station, Mt. Pleasant, Texas (Site M-34)
- R. M. Heskett Station, Mandan, North Dakota (Site M-99).

The boiler designs represented at these facilities included pulverized coal, dry bottom (Sites M-15, M-33, and M-34), cyclone (Site M-1), and traveling grate stoker (Site M-99), while coal types burned included subbituminous (Site M-1) and lignite (all others).

The test programs were designed to measure radionuclide concentrations in all major process streams associated with these five plants. The resulting data are used in combination with plant operating data (nominal and measured) to conduct a radionuclide mass balance for each facility. The accuracy of these balances (in terms of total activity measured in all effluent streams versus total incoming activity) is important in assessing radionuclide emission measurements.

Emission testing was conducted at control device inlet and outlet locations (wherever feasible) using the Source Assessment Sampling System (SASS train), the Andersen High Capacity Sampling System (HCSS train), and the EPA Method 5 train. Emission sample aliquots were shipped along with samples collected from solid and liquid streams to the EPA's radiological test facilities in Montgomery, Alabama and Las Vegas, Nevada. Sample aliquots were also shipped to GCA for measurement of fly ash weights. Solid samples such as coal, limestone, and hopper ash were shipped to Gilbert Associates, Inc., Reading, Pennsylvania, for further analysis (elemental, proximate, and ultimate). The full details of the sampling program are outlined in Section 3.

Our engineering evaluation of the radionuclide emission data is presented in Sections 4 through 8 for each of the five plants, with an overall discussion provided in Section 9. We provide a description of plant operating conditions and discuss the method of calculating emission rates and conducting overall plant radionuclide mass balances. The results of these calculations are presented in each section and the influence of mass balance closure on emission estimate accuracy is described. Supporting data for each of the five plants are presented in Appendices A through E.

To provide backup data for the current evaluation, various solid and liquid stream samples were also collected from the following facilities:

- Nucla Station, Nucla, Colorado (Site M-4)
- Harrington Station, Amarillo, Texas (Site M-16)
- Shawnee Station, Paducah, Kentucky (Site M-18)
- Brunner Island Station, York Haven, Pennsylvania (Site M-19)
- Coal Creek Station, Underwood, North Dakota (Site M-98)

Analytical data for these plants are presented in Appendix F.

To provide further comparative data on the influence of boiler design on radionuclide emissions, we present in Appendix G a summary of radioassay testing which GCA conducted under EPA sponsorship at the Georgetown University fluidized-bed boiler and at the Exxon Miniplant. The Georgetown unit is an industrial size boiler which operates at atmospheric pressure and the Exxon miniplant is a bench-scale pressurized unit.

Since radionuclides are not distributed equally between bottom ash and fly ash, enrichment factors were determined for each radionuclide at each facility. The enrichment factor is defined as the ratio of the concentration of the radionuclide in fly ash to its concentration in coal ash (total ash). The concentration in coal ash is obtained by dividing the measured radionuclide concentration in the coal (pCi/g) by the fractional ash content of the coal.

Mass balances have been determined for each plant for five radionuclides in the uranium decay series (uranium-238, thorium-230, radium-226, lead-210, and polonium-210) and for thorium-232. Half-lives for each of these radionuclides are as follows:[2]

U-238 -- 4.5×10^9 years

Th-230 -- 7.7×10^4 years

Ra-226 -- 1.6×10^3 years

Pb-210 -- 22.3 years

Po-210 -- 138 days

Th-232 -- 1.4×10^{10} years

Since each of the decay products in the uranium series has a half-life significantly less than the parent, secular equilibrium is assumed to exist and for any samples of coal and limestone where one of the daughters was not counted, its activity was assumed equal to that measured for uranium. Due to the extremely short half-life for polonium, corrections were made to the reported activity data to account for the time between date of sampling and date of radionuclide counting (polonium separation).[3] First, an adjustment was made to account for the amount of polonium ingrown from lead, and second, the polonium activity was adjusted back to its activity on the day of sampling.

Other corrections were made to adjust coal activity for the as-received coal moisture content and to correct any fly ash samples reported as pCi/sample back to the original sample weight. In a few cases, sealed fly ash sample packages came apart during shipment and had to be reweighed by the EPA laboratory. In these cases, the new sample weight was used to determine the activity concentration in pCi/g but the original sample weight was retained for calculation of the appropriate mass flow rate.

To manipulate the large volume of data for the five plants, an Apple III microcomputer system together with VisiCalc III software was used. Two major reasons for using the Apple III/VisiCalc program are to ensure a high level of quality control with respect to the numerous, repetetive calculations and to allow for instant recalculation of results when any of several input variables are changed. Since the data are permanently stored on a diskette, further changes in the program as may be requested by EPA, can be easily accommodated.

SECTION 3

SAMPLE COLLECTION AND ANALYSIS

OVERVIEW

Multimedia samples were collected from ten coal-fired steam generators for radionuclide analyses. At five sites, a very intensive program was performed including; flue gas testing, process monitoring and influent and effluent sampling. Sampling at the remaining sites was intentionally brief to provide backup information and only consisted of grab sampling for coal and fly ash. The extensive sampling program was conducted at Sites M-1, M-15, M-33, M-34, and M-99, while abbreviated sampling was carried out at Sites M-4, M-16, M-18, M-19, and M-98. Table 2 provides a summary of the types of samples, the collection method, and analyses performed for the five sites where the extensive program was performed.

The sites were selected based upon the following criteria:

- Utility willingness,
- Previously sampled station,
- Capacity >100 MW,
- Dedicated coal supply,
- Base load unit perferred,
- Dedicated stack; avoid split ducts,
- All ranks of coal (except anthracite) to be represented,
- Particulate control devices limited to ESPs and fabric filters,
- All types of SO_x scrubbers to be represented,
- All forms of fuel feed and bedding to be represented,
- Mature unit if possible, and
- Conventional designs.

TABLE 2. SUMMARY OF SAMPLING CONDUCTED AT SITES WHERE COMPLETE PROGRAM WAS IMPLEMENTED

Sample type	Collection method	Analyses performed
Coal	Grab Composite[a]	Radionuclide, Proximate,[b] Ultimate[c] Mesh Size, Elemental[d]
Bottom Ash	Grab Composite	Radionuclide, Elemental
Makeup Waters	Grab Composite	Radionuclide
Hopper Ash	Grab Composite	Radionuclide, Elemental
Scrubber Reactants	Grab Composite	Radionuclide, Elemental
Filters	SASS/Method 5	Gravimetric, Radionuclide
Thimbles	HCSS	Gravimetric, Radionuclide
Impinger Solutions	SASS/HCSS	Radionuclide

[a] Grab composite refers to hourly grab samples that are composited at the end of the test period.

[b] Proximate analysis: total moisture, volatile matter, fixed carbon, and ash content.

[c] Ultimate analysis: heating value, sulfur, carbon, hydrogen, nitrogen, and oxygen content.

[d] Elemental analysis: aluminum, calcium, iron, magnesium, phosphorous, potassium, silicon, sodium, sulfur, and titanium.

It was originally intended that sampling sites be chosen from a list supplied by EPA that represented all of the above criteria. Additional program requirements called for completion of sampling efforts at each unit in a single day and, where possible, sampling at control device inlet and outlet locations simultaneously with collection of solid grab samples. During the initial plant contacting phase of the program, it became evident that many sites did not wish to participate in the research program and ultimately, site selection was mostly based on willingness of the utility to allow access to the facility. Thus, the types of sources included in the program do not necessarily represent a reasonable cross-section of the coal-fired utility industry.

SAMPLING PROCEDURES

Stack Sampling

Wherever possible, flue gas sampling was conducted at the inlet and outlet of any pollution control device. The purpose of the flue gas testing was to provide size fractionated particulate and condensate for radionuclide analyses. Sampling was conducted using the Source Assessment Sampling System (SASS), the Andersen High Capacity Sampling System (HCSS), and the EPA Method 5 train. Each of these trains is described briefly below. Sample volumes required to be collected were calculated by the EPA Task Officer based on information provided by GCA from the pretest site visit.

Source Assessment Sampling System--

The SASS train features a heated 316SS probe which leads to a cyclone system with cut points of >10 μm, 10 μm to 3 μm, and 3 μm to 1 μm. A 142 mm glass fiber backup filter collects the particles that are less than 1 μm in diameter. The filter assembly is followed by an impinger system for the collection of volatile radionuclides. The first impinger contained 500 ml deionized water, the second impinger contained 500 ml 0.1 N HNO_3, the third was empty, and the final impinger contained 750g of silica gel. The impingers were added to the sample train to determine if any radionuclides were still in the vapor state at the temperature of the sampling location just before the gases were released to the atmosphere.

Physical parameters of the flue gas were measured during the SASS runs with an attached S-type pitot tube and a type K thermocouple. Readings of all SASS train operations and flue gas parameters were recorded every fifteen minutes. Sampling was conducted from a single point of average velocity at a constant flowrate of 4 dry standard cubic feet per minute.

At the end of each run, the sampling train was leak-checked and removed to the GCA truck for sample recovery. Each dry cyclone catch was retained in separate containers. The back up filter was stored in a sealed petri dish. The probe, cyclones and filter assembly were brushed and rinsed with acetone. At outlet locations, where there were minimal amounts of particulate collected, the cyclone rinses were kept separate. Impinger volumes were measured and weight gain was noted prior to transfer to precleaned (nitric acid wash, deionized water rinse) linear polyethylene containers. The impingers were rinsed with deionized water. All flue gas samples were returned to GCA for gravimetric (front half particulate samples) analyses, then dispatched to the appropriate EPA laboratory.

Andersen High Capacity Sampling System--

An HCSS was used for sampling at control device inlet locations. The HCSS is an in-stack, multistage, cascade impactor which adapts to the standard EPA type probe. The HCSS offers three cut sizes between 1.5 and 12 microns. A backup thimble collects particles less than 1.5 micron. The backup thimble was followed by a series of impingers containing: first, 100 ml deionized water; second, 100 ml 0.1 N HNO_3; third, empty; fourth, 250g silica gel.

At the end of the sample run, each of the three impactor stages were rinsed separately with acetone. Impinger volumes were measured, weight gain noted, and the contents were transferred to precleaned linear polyethylene containers. The impingers were then rinsed with deionized water.

EPA Method 5--

The Method 5 train features a stainless steel buttonhook nozzle attached to a heat traced stainless steel probe. At the probe exit, a heated glass fiber filter collects fly ash particulate. The filter is followed by an impinger system containing: first, 100 ml deionized water; second, 100 ml 0.1 N HNO_3; third, empty; final, 250g silica gel. The train was operated in conformance with requirements delineated in 40 CFR 60, Appendix A, Method 5.

EPA Method 3--

Integrated gas samples of flue gas were collected during all SASS and HCSS runs for analysis of O_2, CO_2, and CO with an orsat gas analyzer as per EPA Method 3, 40 CFR 60, Appendix A.

Liquid, Solid and Slurry Sampling

Grab samples of the liquid, solid, and slurry streams were collected and composited on an hourly basis during the flue gas testing. Certain cycling processes did not permit sample collection on a regular hourly basis; in such cases samples were collected as often as cycling would allow. Upon completion of the sample run, composited samples were split into six subsamples. Grab samples were collected in equal volumes and composited to yield a total of approximatey 5 gallons of liquid slurry and 10 pounds of solid at the end of the flue gas testing. In some cases, smaller volumes were collected due to limited availability stemming from the cyclic nature of the process.

Quality Assurance/Quality Control (QA/QC)

QA/QC checks were performed on the sampling and analytical portions of the program (where GCA was directly involved) to ensure collection of valid data. These checks were performed by project participants under the guidance of the QA Manager and Project Manager. GCA's QC program for the sampling aspects of this program included the following:

Equipment Calibration--

All sampling equipment (dry gas meters, pitot tubes, and sample nozzles) were calibrated to specifications outlined in 40 CFR 60, Appendix A.

Use of Designated Sampling Forms--

Standardized data sheets were used for all methods and completed by personnel collecting the samples to ensure that all pertinent information was recorded.

GCA's QC program for laboratory analysis makes use of a number of different types of QC samples such as blanks, duplicates and known and unknown true value QC samples to document the validity of the generated data. The actual QC samples used during this program included:

1. Blank Samples

    a) Field Bias Blanks--Blanks of the filter media and sampling reagents were collected for subsequent analysis.

    b) Method Blanks--Blanks of the filter media were submitted to the EPA laboratories to determine background values of the radionuclides in the filter. (Because the fraction of particulate matter collected on the filter was small in all cases and since the blank correction was also small, data adjusted for the blanks are presented separately from the overall mass balances for each plant in each of the appropriate appendices).

2. QC Samples

    a) QC samples of unknown concentration from the National Bureau of Standards (NBS) were submitted with the coal and fly ash samples sent out for ultimate, proximate and elemental analyses.

Weighings for gravimetric determination of particulate samples were performed on a Mettler balance, Model H 54. The balance was checked with Class S NBS standard weights. Weighing material was dessicated for 24 hours prior to weighing and for at least 6 hours prior to audit (second) weights.

PROCEDURES FOR SAMPLE DISPATCHING

Samples collected during the program were dispatched to various laboratories for analyses. At the conclusion of a sampling period, each sample (with exception of the flue gas samples) was split into six subsets. One subset was made available to the participating utility. On four of the subsets, sample chain of custody was transferred from GCA to four EPA designated laboratories. Those laboratories were:

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Mound Laboratory
Monsanto Research Corporation
Miamisburg, Ohio

U.S. EPA
Eastern Environmental Radiation Facility (EERF)
Montgomery, Alabama

U.S. EPA
Las Vegas Facility (LVF)
Las Vegas, Nevada

These subsamples of the solids, liquid and slurry streams were dispatched to the nearest Federal Express office for overnight delivery within twenty four hours of sample collection. All samples were labeled, identified as a subsample, sealed, accounted for on a packing list, and shipped to the designated laboratories. The remaining subsample and all of the flue gas samples were returned to GCA. From GCA, aliquots of the coal, fly ash, bottom ash and scrubber reactants (when applicable) were submitted to Gilbert Commonwealth in Reading, Pennsylvania for elemental, proximate, and ultimate analysis. Particulate samples were weighed at GCA and dispatched to EERF or LVF for radionuclide analysis.

COMPLETE SAMPLING PROGRAMS

Complete sampling programs were conducted at Sites M-1, M-15, M-33, M-34, and M-99. Specific problems encountered at any of these sites are discussed in Sections 4 through 8 of this report. A summary of sampling locations, sampling equipment, and sample volumes for each facility is presented in Table 3. The impact of actual sample volumes obtained on plant results is discussed in each appropriate section.

ABBREVIATED SAMPLING PROGRAMS

Grab samples of various coal and ash streams were collected as part of abbreviated sampling programs conducted at five additional facilities (Sites M-4, M-16, M-18, M-19, and M-98). The results of the analyses conducted on these samples are presented in Appendix F along with a discussion of how they compare with other program results.

TABLE 3. SAMPLING DATA SUMMARY

Site	Sampling location	Sampling train used	Required sample volume[a] (ft^3)	Actual sample volume (ft^3)	Actual sample time (min)
M-1	Scrubber Inlet (N)	HCSS	177	195	491
	Scrubber Inlet (S)	HCSS	177	153	404
	Scrubber Outlet (N)	SASS	1413	742	210
	Scrubber Outlet (S)	SASS	1413	738	205
M-15	Cyclone Inlet	SASS	706	55	15
	Cyclone Outlet	SASS	706	383	100
	Scrubber Inlet	SASS	706	799	200
	Scrubber Outlet	SASS	883	867	255
M-33	ESP Inlet (N)	HCSS	35	62	240
	ESP Inlet (S)	SASS	-	351	141
	ESP Outlet	SASS	353	909	250
M-34	Scrubber Inlet	SASS &	1766	475	180
	(one of four ducts)	HCSS	-	51	135
	Scrubber Outlet	SASS &	1766	1014	311
		Method 5	-	163	232
M-99	Cyclone Inlet	-	-	-	-
	ESP Inlet (W)	SASS	883	411	200
	ESP Inlet (E)	HCSS	177	116	150
	ESP Outlet	SASS	1766	1843	500

[a] An estimation of the required sample volume was made by considering the following site-specific factors:

- specified activity for minimum detection
- stack flow rate
- coal feed rate
- specific element concentration
- partition coefficient
- control device efficiency
- isotopic abundance
- isotopic specific activity
- sample collector efficiency
- differential particle size fraction

SECTION 4

SITE M-1

PLANT DESCRIPTION

Site M-1 is Unit No. 1 at LaCygne Generating Station in LaCygne, Kansas. The station is operated by Kansas City Power and Light Company. Plant contacts during the sampling program were Jim Wishart who had completed the ORP presurvey forms and Phil Franchett, Results Foreman in the Air Quality Control Section.

Unit No. 1 generates 874 MW (gross) using a Babcock and Wilcox cyclone-fired boiler burning eastern subbituminous coal with high ash and sulfur content. Bottom ash is sluiced out of the wet bottom of the boiler and is sold commercially. Flue gas cleaning is accomplished with a Venturi/Absorber Scrubber system consisting of eight scrubber modules. Flue gas exits the air heaters in two ducts which feed a common inlet plenum before distribution to each of the eight scrubber module inlets. Flue gases discharging from the scrubber system pass through four steam coil reheaters, an outlet plenum, and six induced draft fans before exiting through two ducts to the stack.

A schematic diagram of the plant configuration, including location of sampling points, is provided in Figure 1. A summary of plant design characteristics is given in Table 4.

SAMPLES COLLECTED

Both north and south ducts were sampled at the inlet and outlet of the scrubber system on March 27, 1981. An Andersen High Capacity Sampling System (HCSS) was used at the scrubber inlet while a Source Assessment Sampling System (SASS) was used at the scrubber outlet. Outlet sampling at this site presented an unexpected difficulty; the gas stream was mainly comprised of particles in the one micron and less diameter range. This necessitated filter changes every 30 minutes which quadrupled the time required to collect the necessary sample volume. Unit No. 1 operated at an average load of 688 MW (gross) and a coal feed rate of 304 long ton/hr during the test period.

A composite sample of the incoming coal was collected during the test period. Analysis of this sample gave the following results:

Moisture content, percent	9.52
Ash content, percent	24.2

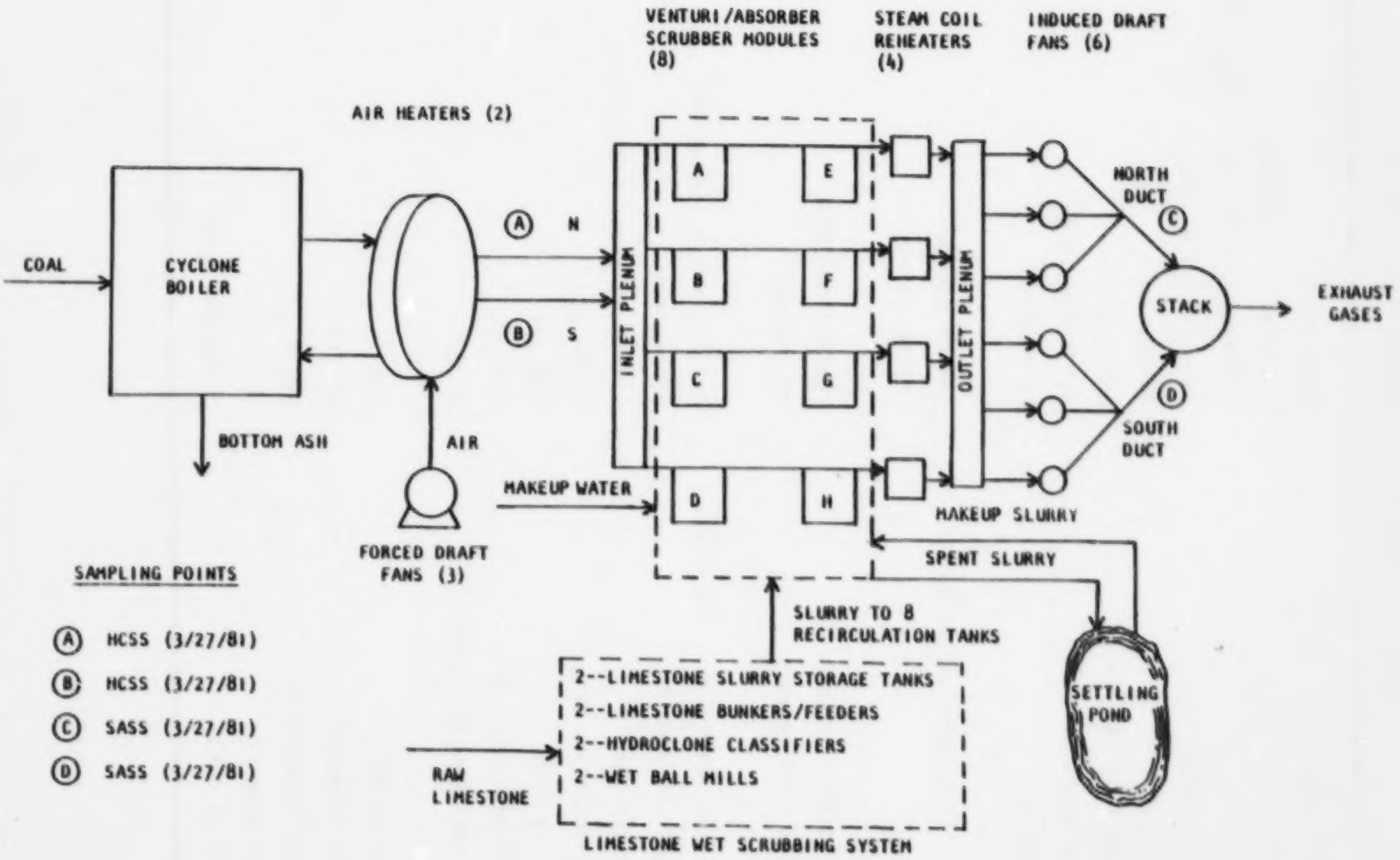

Figure 1. Plant flow diagram, Site M-1.

TABLE 4. DESIGN CHARACTERISTICS, SITE M-1

Boiler type	Base load
Firing mode	Cyclone, wet bottom
Age	Commercial operation - May 1973
Manufacturer	Babcock and Wilcox
Coal type	Bituminous
Design coal feed rate	380 ton/hr
Steam rate	5,757,633 lb/hr
Excess air	15 percent
Electric generating capacity	874 mw (gross) 740 mw (net)
Particulate control	Venturi scrubber
Design efficiency	99 percent
Flue gas desulfurization system	Wet throwaway limestone
Design efficiency	80 percent
Reactant feed	0.2353 lb limestone/lb coal
Recirculation rate	6,500 gpm
Make up rate	200 gpm
Discharge rate	200 gpm
Reactant concentration	46 g/l
Stack height	700 ft.
Stack diameter	26 ft.
Design temperature	190°F
Stack velocity	90 ft/sec
Air flow rate	2,760,000 acfm

Sulfur content, percent	4.66
Heating value, Btu/lb	9,550

Grab samples were taken at all incoming and outgoing streams and composited and fly ash sampling was conducted in both inlet and outlet ducts of the scrubber system. The sampling performed at the scrubber inlet allowed for an accurate estimation of the boiler bottom ash rate. In addition, data made available by plant personnel pertaining to the flue gas desulfurization system enabled accurate quantification of mass flow rates for scrubber inlet and outlet streams (limestone, makeup water, and sludge discharge).

RESULTS

For Site M-1, activity measurements were reported for all samples by EERF along with two-sigma error values. In a few cases, sealed fly ash sample packages sent to EERF came apart during shipment and had to be reweighed by the EPA laboratory. In these cases, the new sample weight was used to determine the activity concentration in pCi/g but the original sample weight was retained for calculation of the appropriate mass flow rate.

All data and results for Site M-1 are presented in Appendix A. The various measured and calculated values for mass flow rates, fly ash weights, sample volumes, etc. are shown in Table A-1. Values determined by calculation (such as limestone and sludge discharge rates) are indicated by an asterisk (*); all other values are either directly or indirectly determined by measurement. Tables A-2 and A-3 show the activity values reported for the six radionuclides for all samples; Table A-2 shows the actual data obtained by EERF (i.e., which samples were less than background or not counted) and Table A-3 shows the values used in the calculations. The individual radionuclide balances are shown in Table A-4 with results obtained by using activity measurements without their corresponding error bands. (There was little difference between results obtained with and without the two-sigma error values.) Table A-5 shows the results obtained by doing a balance around the venturi/absorber scrubber only. This was done to determine approximate activity values for Ra-226, Po-210, and Pb-210, because no data were reported for these radionuclides in the scrubber sludge. Finally, Table A-6 presents filter and thimble (<1 μm) sample results corrected for blank radioactivity. The data presented in Appendix A are summarized in various tables and discussed in the following paragraphs.

As a result of an extensive sampling program, rates for all ash streams were determined with reasonable confidence in their accuracy. Ash flow rates at the various points in the plant including ash input from the coal, bottom ash from the boiler, ash input to the scrubber, and ash discharged from the scrubber to the settling pond and to the atmosphere, are shown in Table 5. The value determined for the bottom ash stream would appear to be somewhat low when compared to a theoretical value of about 80 percent of ash input for a cyclone-fired boiler. Based on the inlet and outlet sampling, the efficiency of the scrubber for fly ash removal is about 98 percent.

TABLE 5. DISTRIBUTION OF ASH PARTICULATE, SITE M-1

Ash stream	Mass flow rate, g/hr (percent of total input)
Input from coal	7.5×10^7
Bottom ash	4.7×10^7 (63)
Scrubber inlet ash	2.8×10^7 (37)
Scrubber ash	2.7×10^7 (36)
Fly ash	5.6×10^5 (0.8)

The distribution of the various radionuclides in these ash streams and the percentage of total input or output is shown in Table 6. For each of the radionuclides, coal is responsible for about 90 percent and limestone about 10 percent of the total input. Most of the radionuclides leave the plant in the boiler bottom ash and the ash discharged by the scrubber. Polonium and lead show the highest percentages in the scrubber ash and fly ash streams. Po-210 shows the highest percentage (23) being emitted to the atmosphere while the others range from 0.5 to 6 percent of input. Lead and polonium show the highest levels in the scrubber ash (88 and 77 percent respectively), while thorium-232 and radium show the highest levels in the bottom ash (52 and 46 percent respectively).

To give an idea as to how the radionuclides are distributed in the fly ash leaving the stack, Table 7 shows the distribution as a function of particle size. Whereas most of the fly ash collected was less than 1 μm in diameter (79 percent), most of the radionuclide emissions were also found in this fraction of the fly ash.

As part of the overall balance analysis, percent closures were computed for each radionuclide and a summary of these results is presented in Table 8. In general, the closures obtained were quite satisfactory given all of the potential errors with respect to sampling, analysis, and computation of various plant parameters. The closures determined with and without the two sigma error values were very similar, thus indicating that the activity analyses were quite accurate. Ra-226 had the lowest percent closure with only about half being accounted for in the plant effluent. Pb-210 yielded the highest results with about one and one-third times as much shown leaving the

TABLE 6. DISTRIBUTION OF RADIONUCLIDES IN ASH, SITE M-1

Radionuclide	Radionuclide input from coal, μCi/hr (percent of total input)	Radionuclide distribution in ash, μCi/hr (percent of total output): Bottom ash	Ash removed by scrubber	Fly ash released to atmosphere
Uranium-238	720 (87)	293 (40)	415 (57)	21 (3)
Radium-226	720 (87)	176 (46)	197 (51)	11 (3)
Polonium-210	720 (87)	0 (0)	600 (77)	175 (23)
Lead-210	720 (87)	66 (6)	950 (88)	60 (6)
Thorium-230	662 (89)	261 (42)	356 (57)	3 (0.5)
Thorium-232	82 (93)	51 (52)	45 (46)	1.5 (1.5)

TABLE 7. DISTRIBUTION OF RADIONUCLIDES IN STACK FLY ASH, SITE M-1

Stack fly ash				Radionuclide emission rate, µCi/hr (percent of total emission)					
Size fraction, (µm)		Weight, (mg)	Percent of total weight	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
>10	N	474	20	2.2	1.8	26	13	0.7	0.08
	S	845		(10.6)	(16)	(15)	(22)	(24)	(5.3)
3-10	N	0.4	0.2	0.02	0.03	0	1.1	0.01	0.002
	S	14		(0.1)	(0.3)	(0)	(1.8))	(0.3)	(0.1)
1-3	N	31	1.0	0.18	0.18	0.9	0.62	0.07	0.01
	S	39		(0.9)	(1.6)	(0.5)	(1.0)	(2.4)	(0.7)
<1	N	2600	79	18.5	8.7	150	45	2.2	1.4
	S	2500		(89)	(79)	(85)	(75)	(74)	(93)
Total		6514	-	21	11	175	60	3.0	1.5
Percent of total plant radionuclide output				(2.9)	(2.8)	(23)	(5.6)	(0.5)	(1.5)

plant as entering. The remaining four radionuclides all showed excellent closures ranging from 83 to 111 percent. Since, in all cases, the incoming coal accounts for about nine-tenths of the total radioactivity coming into the plant, it is obvious that the measured coal activities are critical to the closure analysis. (Because of the similarity between closure percentages with and without the two-sigma error data, only the results using actual activity data are presented in Appendix A, Table A-4).

TABLE 8. CLOSURE DATA FOR RADIONUCLIDE BALANCES, SITE M-1

	Percent closure--(pCi/hr out÷pCi/hr in)x(100)					
Radionuclide balance	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
1. Measured activities used without 2-sigma error values	88.5	46.6	94.3	130.5	83.0	111.4
2. Measured activities used with maximum positive 2-sigma error	88.3	42.4	87.6	123.6	85.6	112.5
3. Measured activities used with maximum negative 2-sigma error	88.7	51.8	102.8	139.1	80.1	109.7

To provide a perspective as to the fate of each of the six radionuclides, a summary is presented in Figure 2. A separate balance was conducted around the scrubber because no activities were reported in the scrubber sludge for radium, polonium, and lead. First, a balance was done on Th-230 and in conjunction with its measured activity, a sludge rate was determined. Using this new sludge rate, balances were done on radium, polonium, and lead and activity concentrations were computed. These computed activities as well as the new sludge discharge rate were then used to repeat all calculations. It is interesting to note that the sludge rate determined by doing a balance around the scrubber on Th-230 was exactly equal to the design rate provided by the plant. This design rate had been reduced by three-fourths (assuming that six of eight scrubber modules would be operating) to coincide with the plant's operating load factor of 77 percent during the sampling period. The data provided in Figure 2 show that most of the material, especially radium, is "lost" in the boiler area.

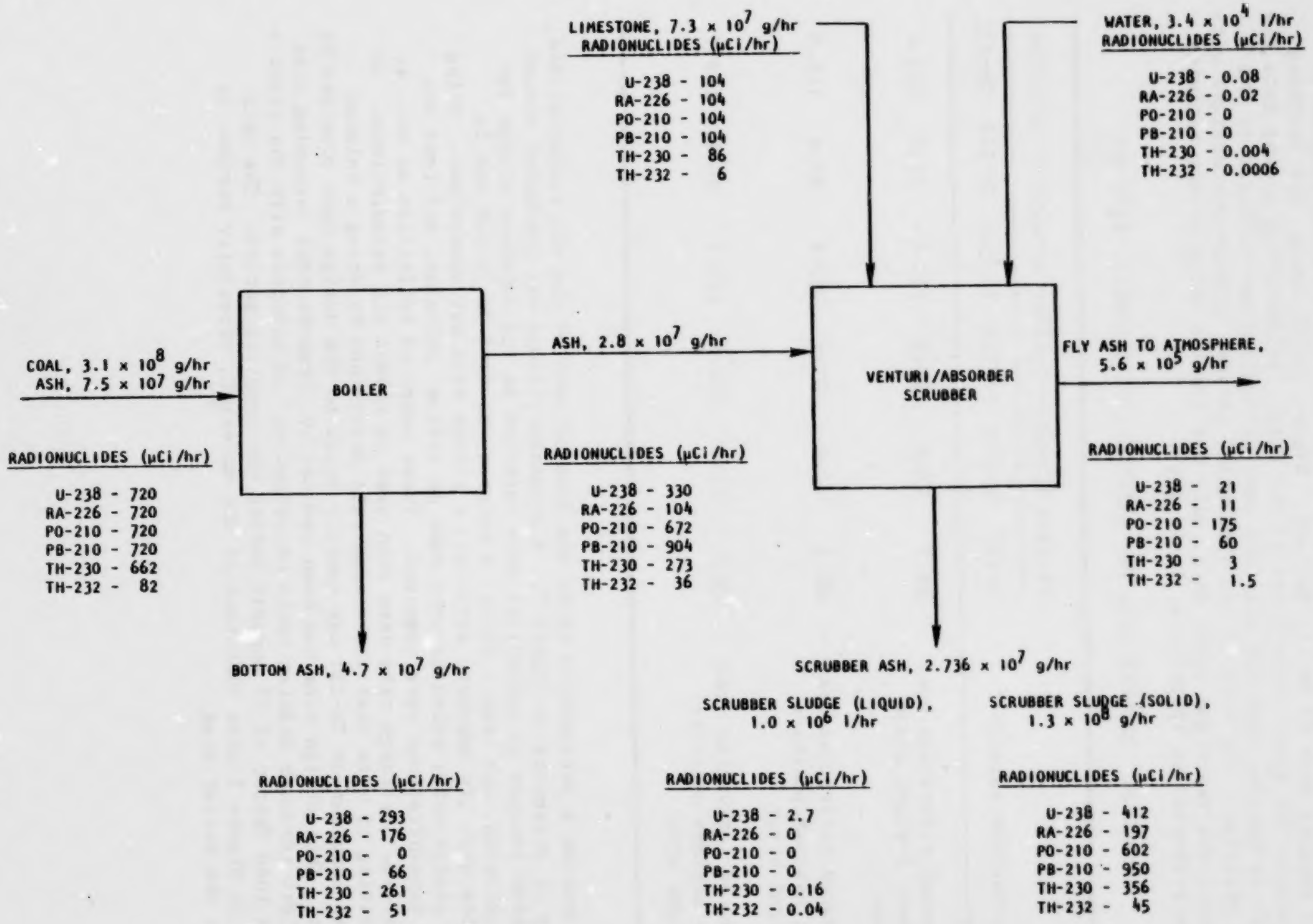

Figure 2. Radionuclide and Ash Distribution Summary, Site M-1.

Enrichment factors have also been calculated for each of the radionuclides. The enrichment factor is defined as the ratio of the radionuclide concentration in the fly ash to its concentration in the coal ash. Computed enrichment factors are as follows:

U-238	3.9
Ra-226	2.0
Po-210	32
Pb-210	11
Th-230	0.6
Th-232	2.4

Results from analysis of the impinger contents at the scrubber inlet and outlet sampling locations are given below and indicate that little, if any, of the radionuclides exit to atmosphere in the vapor state. These results are discussed more fully in Section 9.

	Emission Rate, Ci/hr	
	Scrubber	
	Inlet	Outlet
U-238	4	0.08
Ra-226	1	ND
Po-210	3	ND
Pb-210	20	ND
Th-230	0.3	ND
Th-232	0.08	ND

ND = Not detectable.

SECTION 5

SITE M-15

PLANT DESCRIPTION

Site M-15 is Unit No. 1 at the Lewis and Clark Station in Sidney, Montana which is operated by Montana and Dakota Utilities Company.

Unit No. 1 generates 56 MW (gross) using a tangentially-fired pulverized coal boiler burning Montana lignite with medium ash and low sulfur content. Particulate matter is removed from the flue gas with a multitube cyclone followed by a wet venturi scrubber.

A diagram of the overall plant configuration, including location of sampling points, is provided in Figure 3. A summary of plant design characteristics is given in Table 9.

SAMPLES COLLECTED

Sampling was performed at the inlet and outlet of both collection devices using the Source Assessment Sampling System (SASS). Sampling was conducted around the multitube cyclone on May 1, 1981, and around the venturi scrubber on April 30, 1981. Unit No. 1 operated at a average load of 38 MW (gross) and a coal feed rate of 34.2 short ton/hr during the sampling period.

A composite sample of the incoming coal was collected during the test period. Analysis of this sample gave the following results:

Moisture content, percent	20.5
Ash content, percent	9.14
Sulfur content, percent	0.33
Heating value, Btu/lb	8,071

Grab samples were taken of all incoming and outgoing streams on both sampling dates and composited and these and all fly ash samples were sent to the EPA Laboratory in Las Vegas for radionuclide analysis. Sampling at the multitube cyclone inlet allowed for good approximation of the boiler bottom ash rate while additional data provided by plant personnel enabled accurate quantification of mass flow rates for scrubber inlet and outlet streams.

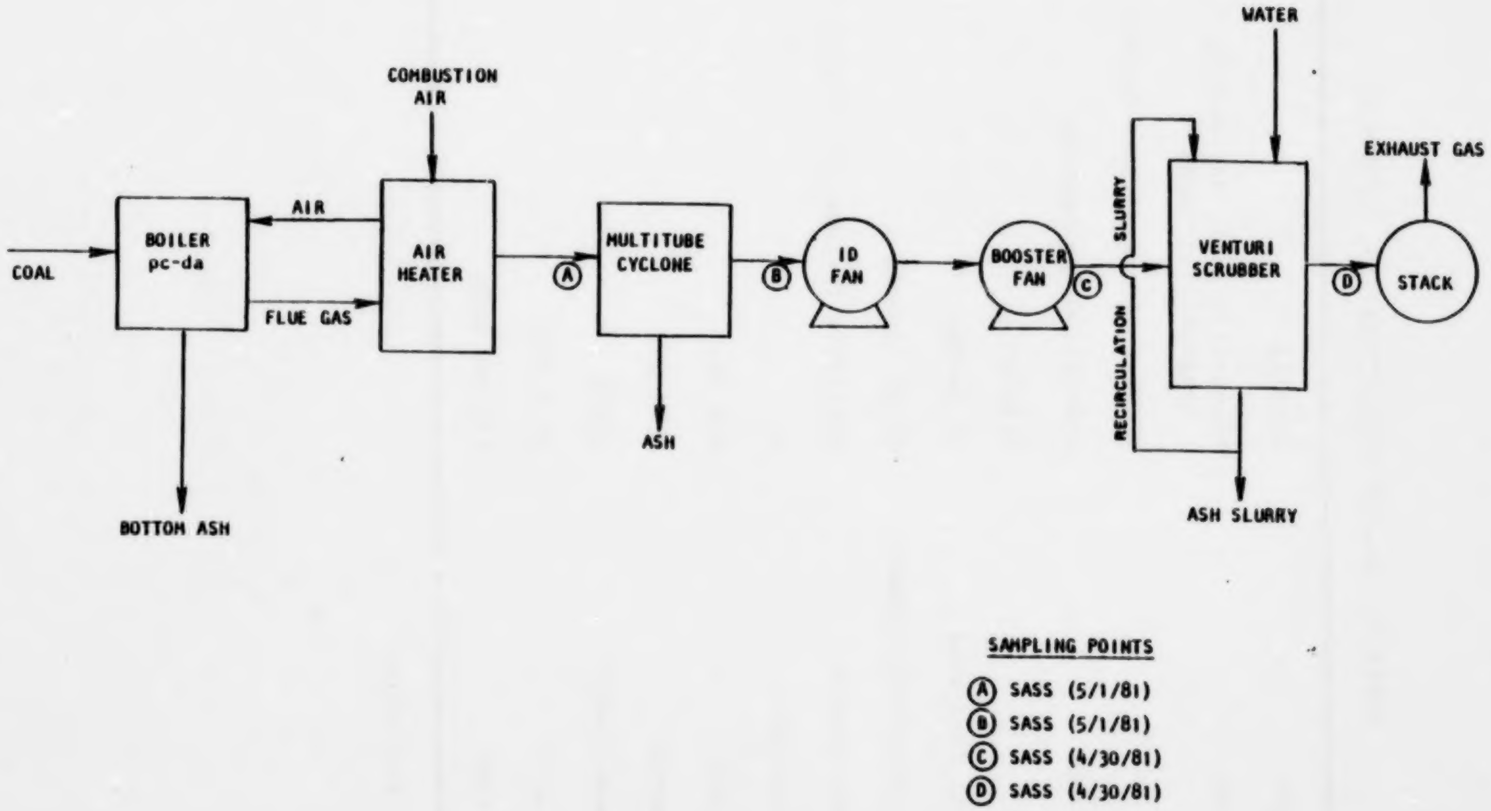

Figure 3. Plant Flow Diagram - Site M-15.

TABLE 9. DESIGN CHARACTERISTICS, SITE M-15

Boiler type	Cycling
Firing mode	Pulverized coal, dry bottom, tangentially-fired
Age	Commercial operation - October 1, 1958
Manufacturer	Combustion Engineering
Coal type	Lignite
Design coal feed rate	51 ton/hr
Electric generating capacity	56 mw (gross)
Particulate control	Multitube cyclone and venturi scrubber
Design efficiency	NA
Stack height	250 ft.
Stack diameter	14.5 ft.
Design temperature	150°F
Stack velocity	27 ft/sec
Air flow rate	270,000 acfm

NA = Data not available.

RESULTS

Radionuclide balances were determined around the plant for each of the radionuclides except lead. The Las Vegas laboratory analyzed these samples but did not have the capability for Pb-210 analysis and, therefore, no values were reported for any of the samples.

All data and results for Site M-15 are presented in Appendix B. The various measured and calculated values for mass flow rates, fly ash weights, sample volumes, etc. are shown in Table B-1. Values determined by calculation (scrubber water and sludge discharge rates) are indicated by an asterisk (*); all other values are either directly or indirectly determined by measurement. Tables B-2 and B-3 show the activity values reported for the radionuclides for all samples. Table B-2 shows the actual data obtained by the EPA Laboratory (i.e., which samples were less than background or not counted) and Table B-3 shows the values used in the calculations. The individual radionuclide balances are shown in Table B-4 with results obtained by using activity measurements without their corresponding error bands. Table B-5 shows radionuclide rates at the mechanical collector inlet and outlet and the scrubber inlet. Finally, Table B-6 presents filter and thimble (<1 μm) sample results corrected for blank radioactivity. The data presented in Appendix B are summarized in various tables and discussed in the following paragraphs.

As a result of an extensive sampling program, rates for all ash streams were determined with reasonable confidence in their accuracy. Ash flow rates at the various points in the plant along with the associated percentage of the total ash input are shown in Table 10. The value determined for the boiler bottom ash stream (28 percent) is not unreasonably different from the theoretical value (20 percent of ash input) that would be expected for a pulverized coal-fired boiler. Based on the inlet and outlet sampling, the efficiency (for fly ash removal) for the multitube cyclone is determined to be about 67 percent while that for the venturi scrubber is 98.6 percent.

The distribution of the various radionuclides in the effluent ash streams and the percentage of total input or output is shown in Table 11. For each of the radionuclides, coal is responsible for essentially all of the input. Most of the radionuclides leave the plant in the mechanical collector ash. Polonium shows the highest fractions in the scrubber hopper ash and fly ash streams. U-238 shows the highest percentage in the cyclone ash (72) while thorium-230 shows the highest percentage in the boiler bottom ash (42).

The distribution of the various radionuclides in the fly ash leaving the stack is given in Table 12 as a function of particle size. The largest fraction of material collected was >10 μm and, except for U-238 and Th-232, most of the radioactivity shows up in this fraction. For U-238 and Th-232, most is present in the <1 μm size fraction. As expected, polonium shows the highest overall fraction of any radionuclide exiting in the fly ash stream (4.2 percent).

TABLE 10. DISTRIBUTION OF ASH PARTICULATE, SITE M-15

Ash stream	Mass flow rate, g/hr (percent of total input)
Input from coal	2.8×10^6
Bottom ash	7.3×10^5 (26)
Cyclone inlet ash	2.1×10^6 (74)
Cyclone hopper ash	1.4×10^6 (49)
Cyclone outlet ash	7.0×10^5 (25)
Scrubber inlet ash	5.3×10^5 (19)
Scrubber hopper ash	5.3×10^5 (18.5)
Fly ash	7,209 (0.25)

TABLE 11. DISTRIBUTION OF RADIONUCLIDES IN ASH, SITE M-15

Radionuclide	Radionuclide input from coal, µCi/hr (percent of total input)	Radionuclide distribution in ash, µCi/hr (percent of total output)			
		Bottom ash	Ash removed by cyclone	Ash removed by scrubber	Fly ash released to atmosphere
Uranium-238	6.2 (99.6)	1.2 (26)	3.4 (72)	0.05 (1.2)	0.4 (0.8)
Radium-226	6.2 (100.0)	1.2 (20)	3.2 (56)	1.3 (22)	0.08 (1.4)
Polonium-210	6.2 (99.9)	0.5 (17)	1.3 (41)	1.2 (38)	0.1 (4.2)
Lead-210	Not counted in any samples				
Thorium-230	6.2 (100.0)	1.8 (42)	2.3 (53)	0.15 (3.5)	0.06 (1.3)
Thorium-232	5.4 (100.0)	0.59 (15)	2.6 (65)	0.8 (20)	0.02 (0.6)

TABLE 12. DISTRIBUTION OF RADIONUCLIDES IN STACK FLY ASH, SITE M-15

Stack fly ash			Radionuclide emission rate, µCi/hr (percent of total emission)					
Size fraction, (µm)	Weight, (mg)	Percent of total weight	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
>10	389	50	0.01 (32)	0.05 (63)	0.06 (48)	--- ---	0.04 (62)	0.005 (20)
3-10	11	1.4	0.0003 (0.8)	0.0007 (0.9)	0.0008 (0.6)	--- ---	0.0004 (0.7)	0.0003 (1.2)
1-3	174	22	0.007 (20)	0.009 (11)	0.02 (14)	--- ---	0.0055 (9.5)	0.003 (13)
<1	210	27	0.02 (47)	0.02 (25)	0.05 (37)	--- ---	0.02 (28)	0.02 (66)
Total	784	---	0.04	0.08	0.13	---	0.06	0.02
Percent of total plant radionuclide output			(0.8)	(1.4)	(4.2)	---	(1.3)	(0.6)

As part of the overall balance analysis, percent closures were computed for each radionuclide; a summary of these results is presented in Table 13. The best results were obtained for radium (~93 percent) while the poorest closure was evident for polonium (~52 percent). For each of the other radionuclides, about three-fourths of the material was detected in the output. (Because of the similarity between closure percentages with and without the two-sigma error data, results obtained by using activity measurements without their corresponding error bands are presented in Appendix B, Table B-4).

TABLE 13. CLOSURE DATA FOR RADIONUCLIDE BALANCES, SITE M-15

	Percent closure--(pCi/hr out÷pCi/hr in)x(100)					
Radionuclide balance	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
1. Measured activities used without 2-sigma error values	75.7	93.1	52.0	-	69.8	73.4
2. Measured activities used with maximum positive 2-sigma error	76.1	93.2	52.1	-	70.0	73.5
3. Measured activities used with maximum negative 2-sigma error	75.3	92.9	51.8	-	69.6	73.2

An overall summary of the fate of each of the radionuclides is presented in Figure 4. By looking at individual balances around specific parts of the plant (boiler, cyclone, and scrubber) it is noted that good closures are obtained around the boiler and the cyclone while poorer results are seen around the scrubber. In the case of U-238, the scrubber slurry (spent solid) sample was lost and there is probably much more U-238 than indicated leaving the plant in the scrubber ash stream. The calculated values used for scrubber effluent rates (rather than measured rates) may also partly explain the generally low closures found around the venturi scrubber.

Enrichment factors computed for each radionuclide are as follows:

U-238	2.4
Ra-226	5.2
Po-210	8.6
Pb-210	NC
Th-230	3.7
Th-232	1.7

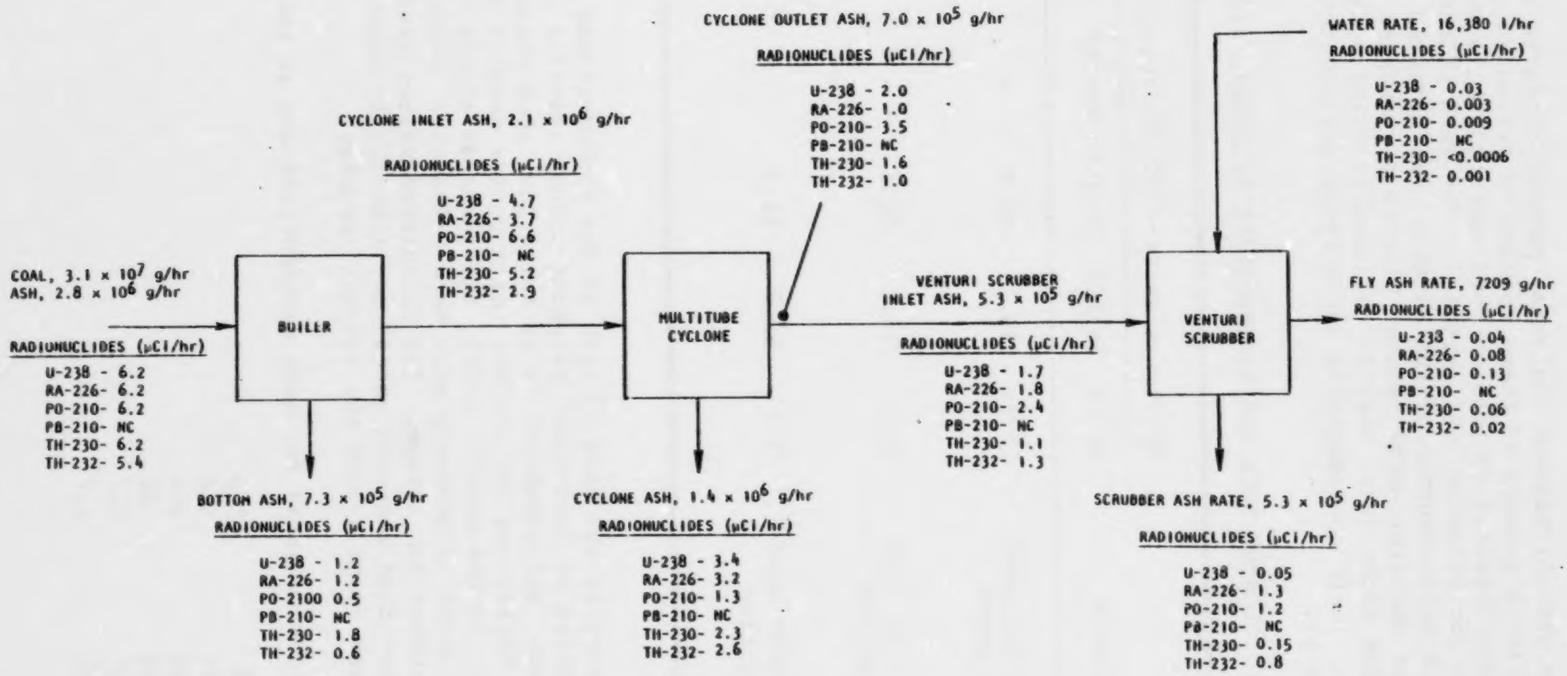

Figure 4. Radionuclide and ash distribution summary, site M-15.

Results from analysis of the impinger contents at the mechanical collector inlet and scrubber outlet sampling locations are given below and indicate that little, if any, of the radionuclides exit to atmosphere in the vapor state. These results are discussed more fully in Section 9.

	Emission Rate, μCi/hr	
	Mechanical Collector Inlet	Scrubber Outlet
U-238	ND	ND
Ra-226	ND	ND
Po-210	ND	ND
Pb-210	NA	NA
Th-230	0.02	0.01
Th-232	ND	ND

ND = Not detectable.

NA = No analysis.

SECTION 6

SITE M-33

PLANT DESCRIPTION

Site M-33 is Unit No. 2 at the Big Brown Station in Fairfield, Texas, which is operated by Texas Utilities Company.

Unit No. 2 generates 593 MW (gross) using a pulverized coal, dry bottom boiler burning Texas lignite with high ash and low sulfur content. Particulate matter is removed from the flue gas with a cold-side electrostatic precipitator (ESP) designed for 89^+ percent removal efficiency.

A diagram of the overall plant configuration, including location of sampling points, is provided in Figure 5. A summary of plant design characteristics is given in Table 14.

SAMPLES COLLECTED

The north and south ducts at the ESP inlet and the ESP outlet were sampled on May 28, 1981. The south inlet duct and the outlet were sampled with a Source Assessment Sampling System (SASS) while an Andersen High Capacity Sampling System (HCSS) was used at the north inlet duct. A minor operational problem was encountered with the SASS train at the south inlet duct; due to high negative pressure and grain loading there was difficulty in sampling at the proper flow rate (4.0 cfm). To ensure isokinetic sampling, the nozzle was changed and the flow rate lowered thus raising the cut sizes in the SASS cyclones. During the test period, Unit No. 2 operated at an average load of 553 MW (gross) and a coal feed rate of 433 short ton/hr. A composite sample of the incoming coal was collected during the test period. Analysis of this sample gave the following results:

Moisture content, percent	20.6
Ash content, percent	15.1
Sulfur content, percent	0.6
Heating value, Btu/lb	7,957

Grab samples were taken at all incoming and outgoing streams and composited and fly ash sampling was conducted in both ESP inlet ducts and the outlet duct. The sampling performed at the ESP inlet allowed for an accurate estimation of the boiler bottom ash rate. Although samples were taken of the bottom ash sluice water, accurate data pertaining to the sluice water rate

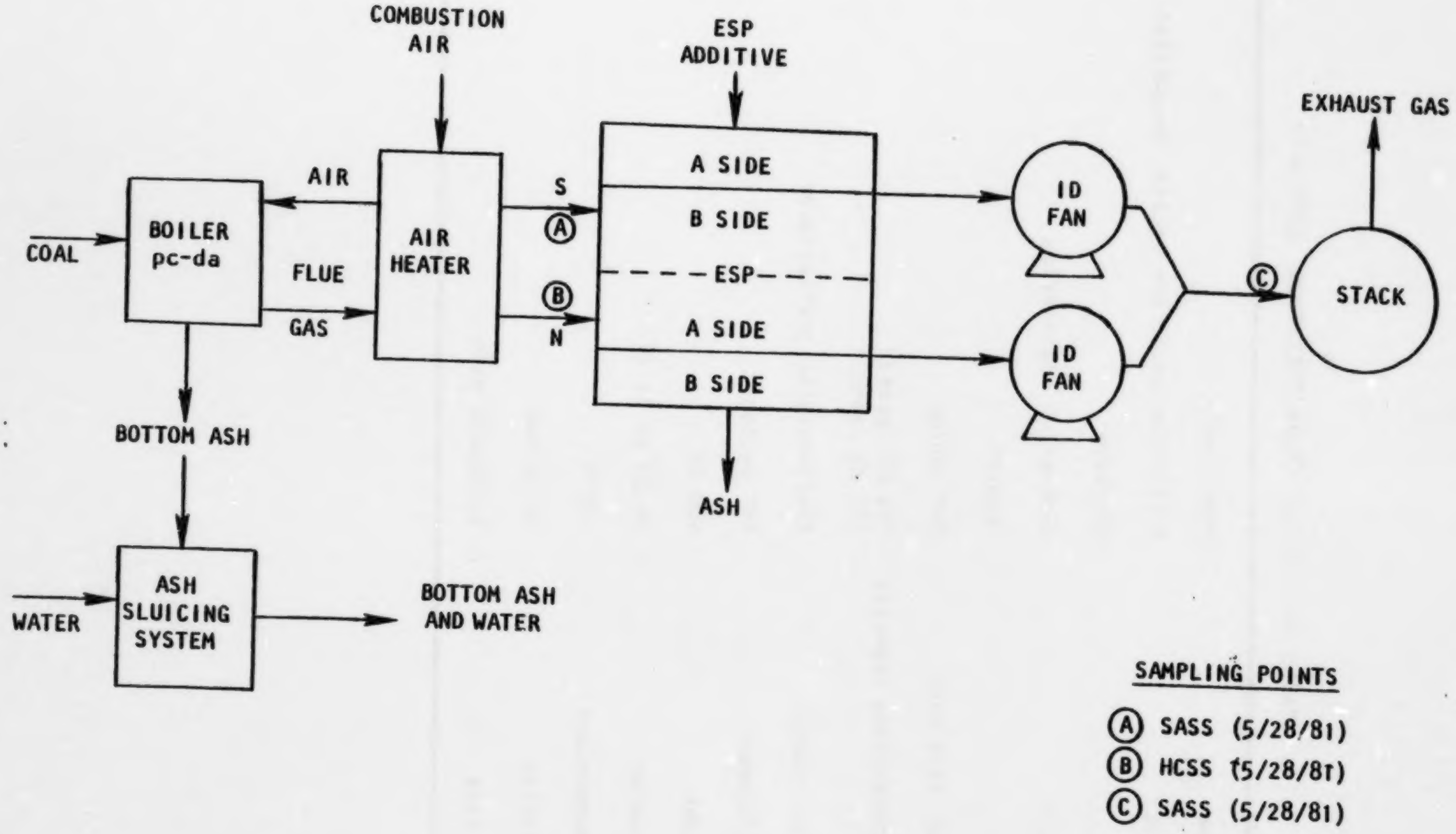

Figure 5. Plant Flow Diagram - Site M-33.

TABLE 14. DESIGN CHARACTERISTICS, SITE M-33

Boiler type	Base load
Firing mode	Pulverized coal, dry bottom, tangentially-fired
Age	10 years
Manufacturer	Combustion Engineering
Coal type	Lignite
Design coal feed rate	530 ton/hr
Electric generating capacity	593 MW (gross) 575 MW (net)
Particulate control	Electrostatic precipitator
Design efficiency	98^+ percent
Stack height	400 ft
Stack diameter	24.25 to 21 ft
Design temperature	350°F
Stack velocity	90 ft/sec
Air flow rate	2,200,000 acfm

were not available. As a means of estimating the bottom ash sluice water rate, a balance was performed around the boiler on Th-230 and a water rate was determined using the reported Th-230 activities in the bottom ash stream.

RESULTS

Radionuclide balances were determined for each of the six radionuclides based on activities reported by EPA's EERF.

All data and results for Site M-33 are presented in Appendix C. The various measured and calculated values for mass flow rates, fly ash weights, sample volumes, etc. are shown in Table C-1. Values determined by calculation, such as bottom ash water sluice rate, are indicated by an asterisk (*); all other values are either directly or indirectly determined by measurement. Tables C-2 and C-3 show the activity values reported for the radionuclides for all samples; Table C-2 shows the actual data obtained by EERF (i.e., which samples were less than background or not counted) and Table C-3 shows the values used in the calculations. The individual radionuclide balances are shown in Table C-4 with results obtained by using activity measurements without their corresponding error bands. Table C-5 presents radionuclide data for the ESP inlet and the results of the Th-230 balance around the boiler. Lastly, Table C-6 presents filter and thimble (<1 μm) sample results corrected for blank radioactivity. The data presented in Appendix C are summarized in various tables and discussed in the following paragraphs.

Extensive sampling enabled determination of all ash stream mass flow rates with reasonable confidence in their accuracy. Ash flow rates at the various points in the plant along with the associated percentage of the total ash input are shown in Table 15. The boiler bottom ash rate is significantly higher than the theoretical value (20 percent of the ash input) that would be expected for a pulverized coal-fired boiler. Based on the inlet and outlet sampling, the efficiency (for fly ash removal) for the ESP is about 97 percent.

The distribution of the various radionuclides in the effluent ash streams is shown in Table 16. Coal accounts for essentially all of the input for each radionuclide. Most of the radionuclides leave the plant in the boiler bottom ash stream. For radium and (especially) lead, much more is shown leaving in the bottom ash than entering with the coal. Polonium shows the highest fractions in the ESP hopper ash and fly ash streams (97 and 2.9 percent of total output, respectively).

The distribution of the various radionuclides in the stack fly ash is given in Table 17 as a function of particle size. Most of the fly ash collected was >10 μm (49 percent) and in the range of 3-10 μm (36 percent). Except for polonium, most of the radioactivity was found in these fractions. Most of the polonium detected in the fly ash was found in the 1-3 μm range.

As part of the overall balance analysis, percent closures were computed for each radionuclide; a summary of these results is presented in Table 18. The best results were obtained for thorium-230 (99 percent) while the poorest

TABLE 15. DISTRIBUTION OF ASH PARTICULATE, SITE M-33

Ash stream	Mass flow rate, g/hr (percent of total input)
Input from coal	5.9×10^7
Bottom ash	3.9×10^7 (66)
ESP inlet ash	2.0×10^7 (34)
ESP hopper ash	1.9×10^7 (32.8)
Fly ash	5.7×10^5 (1.0)

TABLE 16. DISTRIBUTION OF RADIONUCLIDES IN ASH, SITE M-33

	Radionuclide input from coal, µCi/hr (percent of total input)	Radionuclide distribution in ash, µCi/hr (percent of total output)		
Radionuclide		Bottom Ash	Ash removed by ESP	Ash released to atmosphere
Uranium-238	440 (100)	294 (81)	68 (19)	2.4 (0.7)
Radium-226	440 (100)	585 (88)	78 (12)	2.3 (0.4)
Polonium-210	440 (100)	0 (0)	131 (97)	3.9 (2.9)
Lead-210	440 (100)	1,054 (90)	108 (9.3)	5.2 (0.4)
Thorium-230	393 (100)	328 (84)	61 (16)	2.1 (0.5)
Thorium-232	283 (100)	221 (84)	41 (16)	1.4 (0.5)

TABLE 17. DISTRIBUTION OF RADIONUCLIDES IN STACK FLY ASH, SITE M-33

Stack fly ash			Radionuclide emission rate, μCi/hr (percent of total emission)					
Size fraction, (μm)	Weight, (mg)	Percent of total weight	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
>10	3,224	49	0.7 (32)	1.2 (51)	0.03 (0.9)	2.3 (44)	0.9 (45)	0.6 (42)
3-10	2,400	36	0.9 (40)	0.8 (34)	1.1 (27)	2.2 (43)	0.7 (36)	0.5 (37)
1-3	869	13	0.5 (21)	0.3 (12)	1.7 (43)	0.7 (13)	0.3 (13)	0.2 (14)
< 1	130	2	0.2 (7.4)	0.09 (3.7)	1.1 (29)	0 (0)	0.1 (5.6)	0.1 (7.0)
Total	6,622	--	2.4	2.3	3.9	5.2	2.1	1.4
Percent of total plant radionuclide output			(0.7)	(0.4)	(2.9)	(0.4)	(0.5)	(0.5)

results were obtained for lead (265 percent) and radium (150 percent). The primary reason for the high closures on lead and radium were the high activities which were reported for the bottom ash stream. Percent closures for the other three radionuclides were 83, 31, and 93 percent for uranium, polonium, and thorium-232, respectively. Closure data presented in Appendix C, Table C-4, are for results using actual activity measurements without the error data.

TABLE 18. CLOSURE DATA FOR RADIONUCLIDE BALANCES, SITE M-33

	Percent closure--(pCi/hr out÷pCi/hr in)x(100)					
Radionuclide balance	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
1. Measured activities used without 2-sigma error values	82.8	151	30.6	265	99.4	93.2
2. Measured activities used with maximum positive 2-sigma error	92.9	145	32.4	431	111.4	106.5
3. Measured activities used with maximum negative 2-sigma error	70.3	158	28.4	60.7	85.6	77.7

An overall summary of the fate of each of the radionuclides is presented in Figure 6. In general, closures around the ESP were quite good although some polonium is unaccounted for. Closures around the boiler are rather poor and it would appear that levels reported in the bottom ash are probably the most inaccurate.

Enrichment factors determined from the reported data are as follows:

U-238	0.6
Ra-226	0.6
Po-210	0.9
Pb-210	1.2
Th-230	0.5
Th-232	0.5

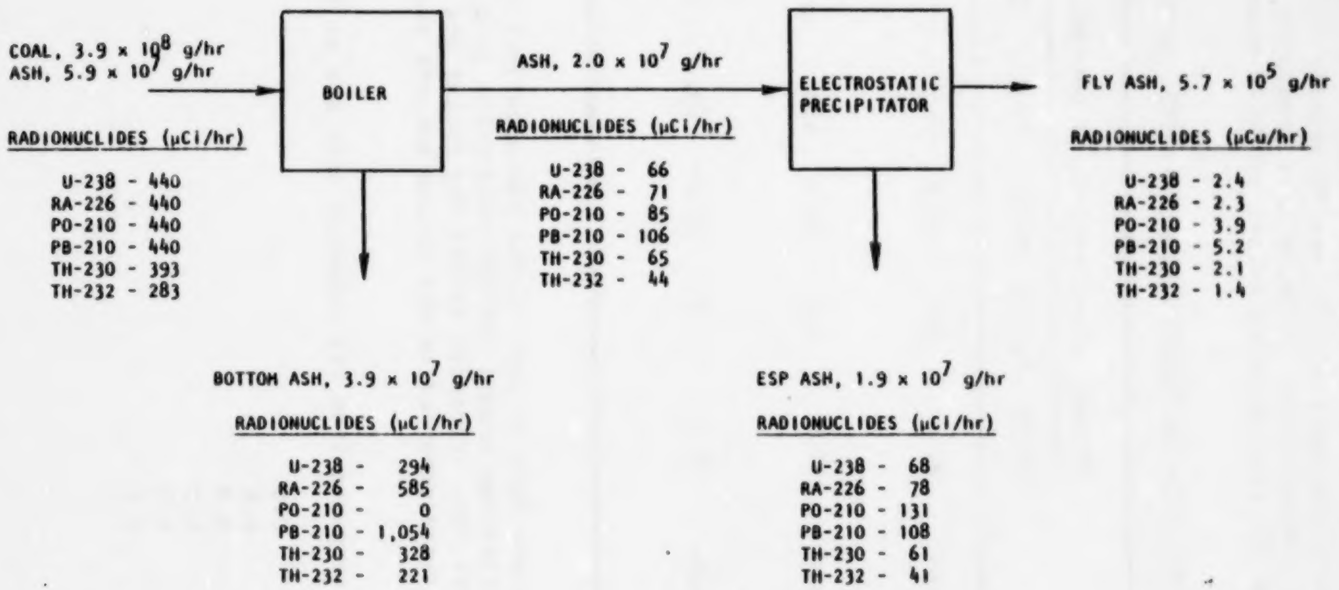

Figure 6. Radionuclide and Ash Distribution Summary, Site M-33.

Results from analysis of the impinger contents at the ESP inlet and outlet sampling locations are given below and indicate that little, if any, of the radionuclides exit to atmosphere in the vapor state. These results are discussed more fully in Section 9.

	Emission Rate, Ci/hr	
	ESP Inlet	ESP Outlet
U-238	0.1	ND
Ra-226	ND	ND
Po-210	0.3	ND
Pb-210	ND	ND
Th-230	ND	ND
Th-232	ND	ND

ND = Not detectable.

SECTION 7

SITE M-34

PLANT DESCRIPTION

Site M-34 is Unit No. 3 at Monticello Generating Station in Mt. Pleasant, Texas, which is operated by Texas Utilities Company.

Unit No. 3 generates 800 MW (gross) using a Babcock and Wilcox, tangentially-fired, pulverized coal, dry-bottom boiler burning Texas lignite with high ash and low sulfur content. Flue gas cleaning is accomplished with an electrostatic precipitator (ESP) and a wet limestone scrubber. Flue gas exiting the boiler passes through an air heater before entering the ESP through two ducts. The gas stream exits the ESP through four ducts and enters the limestone scrubber before discharging through one duct to the stack.

A schematic diagram of the plant configuration, including location of sampling points, is provided in Figure 7. A summary of plant design characteristics is given in Table 19.

SAMPLES COLLECTED

Sampling was conducted in the outlet duct to the stack and in one of the four scrubber inlet ducts on June 4, 1981. A Source Assessment Sampling System (SASS) followed by an Andersen High Capacity Sampling System (HCSS) were used at the scrubber inlet duct while a SASS train followed by a Method 5 train were used at the scrubber outlet. A great deal of difficulty was encountered while sampling at this site. The requirement that GCA personnel be off the site by 6 p.m., frequent thunderstorms, losses of power, and equipment problems all adversely affected the overall sampling program. At the scrubber inlet, problems with the dry gas meter were encountered and the SASS run was terminated and continued with the Andersen HCSS. Loss of electrical power at the 300-ft level of the stack also forced a termination of the outlet SASS run necessitating completion with the Method 5 train. Consequently, the required sample volumes were not collected at either location. Unit No. 3 operated at an average load of 722 MW (gross) and a coal feed rate of 646 short ton/hr during the test period.

A composite sample of the incoming coal was collected during the test period. Analysis of this sample gave the following results:

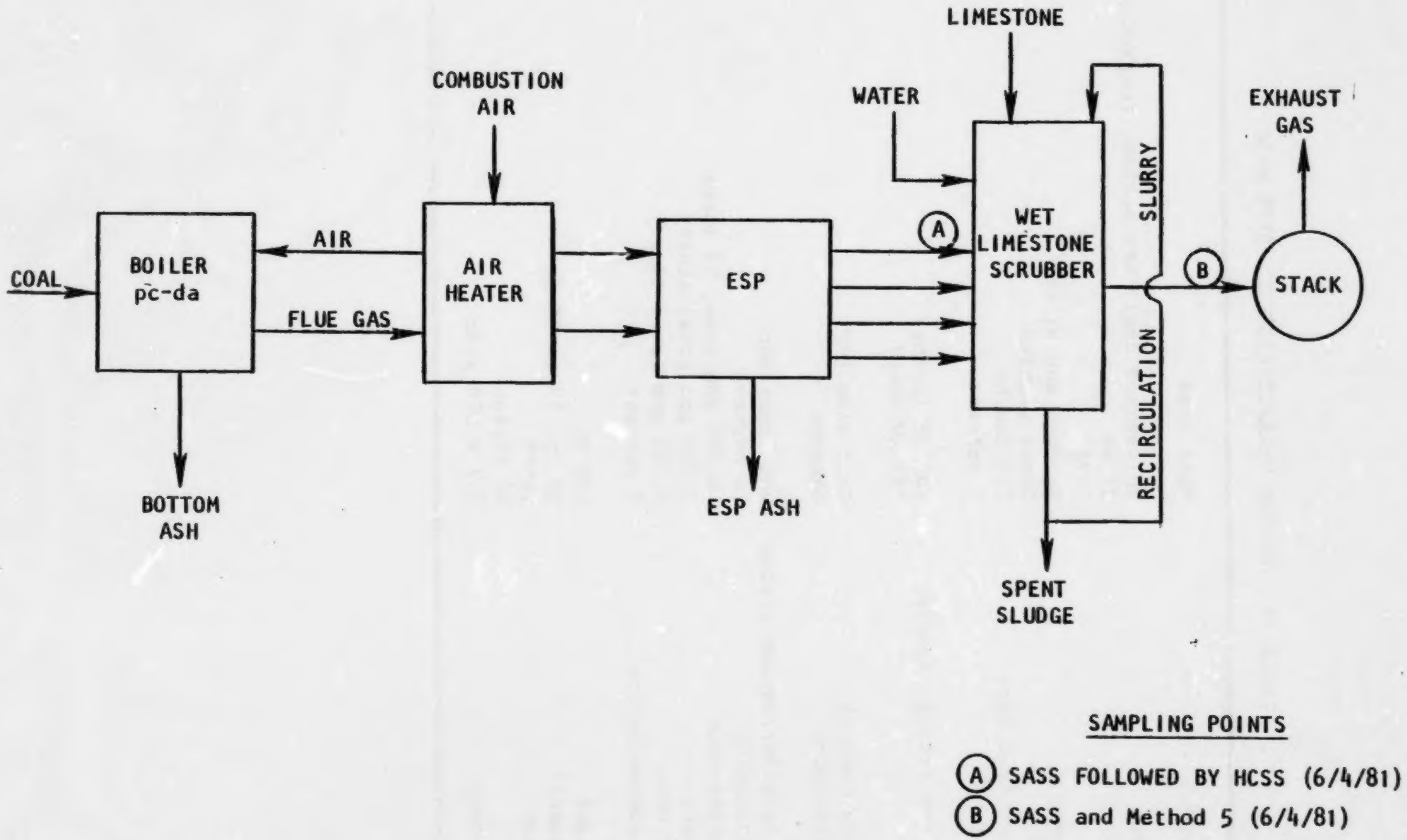

Figure 7. Plant Flow Diagram - Site M-34.

TABLE 19. DESIGN CHARACTERISTICS, SITE M-34

Boiler type	Base Load
Firing mode	Pulverized coal, dry bottom, tangentially-fired
Age	1978
Manufacturer	Babcock and Wilcox
Coal type	Texas lignite
Design coal feed rate	716 ton/hr
Excess air	3 percent
Electric generating capacity	800 MW (gross) 750 MW (net)
Particulate control	Cold side ESP
Design efficiency	Unknown
Flue gas desulfurization system	wet limestone
Design efficiency	74 percent
Recirculation rate	16,000 gpm/pump, 12 pumps
Make up rate	5,585 gpm total slurry
Discharge rate	5,585 gpm total slurry
Reactant concentration	8 percent
Stack height	600 ft
Stack diameter	28 ft, 5" to 25 ft
Temperature	215°F
Velocity	88 ft/sec
Air flow rate	3.3×10^6 acfm

Moisture content, percent	21.1
Ash content, percent	23.1
Sulfur content, percent	0.49
Heating value, Btu/lb	6,738

Grab samples were taken and composited at all incoming and outgoing streams with the exception of the ESP hopper ash stream. (In the absence of radionuclide data for the ESP hopper ash stream, activities reported for the EPS ash from Site M-33 were used since the plant configurations up to the ESP, the boiler type, and the fuel burned are all similar). Since no sampling was performed at the ESP inlet, the boiler bottom ash rate, the ESP ash inlet rate, and the ESP hopper ash rate were all estimated by assuming the bottom ash rate was 20 percent of total ash input. In addition, since only one of four scrubber inlet ducts was sampled, the total fly ash rate at the scrubber inlet was estimated by multiplying the ash rate measured in the sampled duct by the ratio of total flow in the outlet duct to total flow in the sampled inlet duct. No information was available from the plant to aid in further defining any of these fly ash streams.

RESULTS

Mass balances were determined for each of the six radionuclides based on activities reported by EPA's EERF.

All data and results for Site M-34 are presented in Appendix D. The various measured and calculated values for mass flow rates, fly ash weights, sample volumes, etc. are shown in Table D-1. Values determined by calculation are indicated by an asterisk(*); all other values are either directly or indirectly determined by measurement. Tables D-2 and D-3 show the activity measurements reported by the EPA laboratory (i.e., which samples were less than background or not counted) and the values used in the calculations, respectively. Individual radionuclide balance results are shown in Table D-4 while Table D-5 presents radionuclide data for the scrubber inlet. Finally, Table D-6 presents filter and thimble (<1 μm) sample results corrected for blank radioactivity. The data presented in Appendix D are summarized in various tables and discussed in the following paragraphs.

Due to the lack of sampling in all collector inlet ducts and the aforementioned sampling problems encountered, the results obtained are less accurate than those for the first three sites discussed (M-1, M-15, and M-33). Ash flow rates at the various points in the plant along with the associated percentage of the total ash input are shown in Table 20. Based on the sampling conducted and the various assumptions made, the fly ash removal efficiency for the ESP is 99.9 percent while that for the scrubber is 74 percent.

TABLE 20. DISTRIBUTION OF ASH PARTICULATE, SITE M-34

Ash stream	Mass flow rate, g/hr (percent of total input)
Input from coal	1.4×10^8
Bottom ash	2.7×10^7 (20)
ESP inlet ash	1.084×10^8 (80)
ESP hopper ash	1.083×10^8 (79.9)
Scrubber inlet ash	1.1×10^5 (0.01)
Scrubber ash	8.1×10^4 (0.06)
Fly ash	2.8×10^4 (0.02)

The distribution of the various radionuclides in the effluent ash streams is shown in Table 21. Coal accounts for essentially all of the input for each radionuclide with a minor amount being contributed by the limestone added to the scrubber. Most of the radionuclides leave the plant in the ESP and bottom ash streams while very minor amounts are removed by the scrubber or released to the atmosphere.

The distribution of the various radionuclides in the stack fly ash is given in Table 22 as a function of particle size. Because of the noted stack sampling problems, low sample volumes and correspondingly low fly ash weights were collected. Accordingly, the radionuclide emissions were quite small. Emissions of lead and radium were the highest of the six radionuclides.

As part of the overall balance analysis, percent closures were computed for each radionuclide; a summary of these results is presented in Table 23. The closure percentages obtained were generally poor; for polonium and lead about three-fourths of the material was accounted for while for the remaining radionuclides, only about one-half was detected in the effluent streams. Closure data presented in Appendix D, Table D-4 are for results obtained by using activity measurements without their corresponding error bands.

An overall summary of the fate of each radionuclide is presented in Figure 8. Since no ESP inlet data were available, the rates indicated at the boiler outlet were determined by difference. Due to the fact that radionuclides were not counted in the ESP hopper ash, activities for the ESP ash were assumed to be the same as those for Site M-33. Since most of the radionuclides are unaccounted for around the ESP, it is likely that actual ESP hopper ash activities are higher than indicated. A balance around the scrubber also indicates poor closure and is possibly attributed to the fact that only one of four inlet ducts was sampled. Although total air flow and fly ash rate for the scrubber inlet were estimated in proportion to the total flow measured in the outlet and inlet ducts, it is likely that the flow of ash (and hence, radionuclides) through the four inlet ducts is significantly different. Thus, the estimated efficiencies for both particulate collectors are probably inaccurate.

Enrichment factors determined for each of the radionuclides are as follows:

U-238	1.2
Ra-226	2.5
Po-210	2.5
Pb-210	22
Th-230	1.1
Th-232	1.5

TABLE 21. DISTRIBUTION OF RADIONUCLIDES IN ASH, SITE M-34

Radionuclide	Radionuclide input from coal, µCi/hr (percent of total input)	Radionuclide distribution in ash, µCi/hr (percent of total output)			
		Bottom ash	Ash removed by ESP	Ash removed by scrubber	Ash released to atmosphere
Uranium-238	974 (99.6)	73 (16)	381 (84)	0.08 (0.02)	0.2 (0.05)
Radium-226	974 (99.6)	100 (19)	433 (81)	0.08 (0.01)	0.5 (0.1)
Polonium-210	974 (99.6)	0 (0)	729 (100)	0 (0)	0.5 (0.07)
Lead-210	974 (99.6)	124 (17)	602 (83)	0 (0)	4.3 (0.6)
Thorium-230	933 (99.6)	69 (17)	339 (83)	0.06 (0.01)	0.2 (0.05)
Thorium-232	651 (99.9)	54 (19)	230 (81)	0.005 (0)	0.2 (0.07)

TABLE 22. DISTRIBUTION OF RADIONUCLIDES IN STACK FLY ASH, SITE M-34

Stack fly ash			Radionuclide emission rate, μCi/hr (percent of total emission)					
Size fraction, (μm)	Weight, (mg)	Percent of total weight	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
>10	40	22	0.01 (5.5)	0.1 (21)	0.03 (6.7)	1.4 (33)	0.02 (11)	0.004 (2.1)
3-10	72	40	0.05 (20)	0.1 (24)	0 (0)	1.8 (43)	0.05 (24)	0.02 (11)
1-3	42	23	0.05 (19)	0.1 (20)	0 (0)	1.0 (24)	0.02 (10)	0.02 (10)
<1	26	15	0.1 (56)	0.18 (35)	0.5 (93)	0 (0)	0.1 (56)	0.15 (77)
Total	180	--	0.2	0.5	0.5	4.3	0.2	0.2
Percent of total plant radionuclide output			(0.05)	(0.1)	(0.07)	(0.6)	(0.05)	(0.07)

TABLE 23. CLOSURE DATA FOR RADIONUCLIDE BALANCES, SITE M-34

	Percent closure--(pCi/hr out+pCi/hr in)x(100)					
Radionuclide balance	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
1. Measured activities used without 2-sigma error values	46.5	54.6	74.6	74.7	43.6	43.7
2. Measured activities used with maximum positive 2-sigma error	46.9	50.5	78.9	86.3	43.5	43.6
3. Measured activities used with maximum negative 2-sigma error	46.0	59.7	69.3	60.5	43.7	43.8

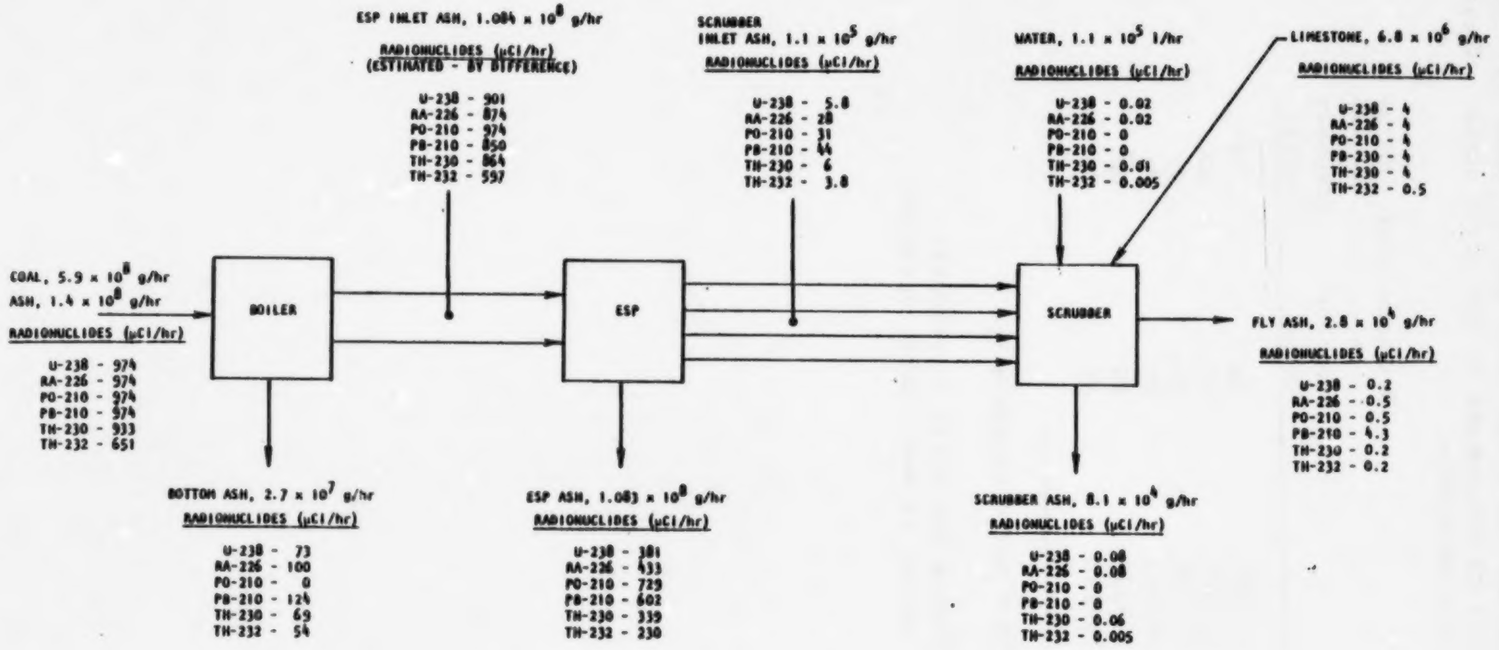

Figure 8. Radionuclide and Ash Distribution Summary, Site M-34.

Results from analysis of the impinger contents at the scrubber inlet and outlet sampling locations are given below and indicate that little, if any, of the radionuclides exit to atmosphere in the vapor state. These results are discussed more fully in Section 9.

	Emission Rate, μCi/hr	
	Scrubber Inlet	Scrubber Outlet
U-238	ND	9[a]
Ra-226	ND	ND
Po-210	0.4	ND
Pb-210	ND	ND
Th-230	ND	ND
Th-232	ND	ND

ND = Not detectable.

[a] Value for U-238 in scrubber outlet is most likely erroneous.

SECTION 8

SITE M-99

PLANT DESCRIPTION

Site M-99 is Unit No. 2 at the R. M. Heskett Station in Mandan, North Dakota, which is operated by Montana and Dakota Utilities Company.

Unit No. 2 generates 75 MW (gross) using a traveling grate, stoker-fired boiler burning North Dakota lignite with medium ash and medium sulfur content. Particulate control consists of a mechanical collector followed by an electrostatic precipitator.

A diagram of the overall plant configuration, including location of sampling points, is provided in Figure 9. A summary of plant design characteristics is given in Table 24.

SAMPLES COLLECTED

Sampling was performed at the inlet and outlet of the ESP on May 4, 1981. Sampling was conducted in the west inlet duct and outlet duct using the Source Assessment Sampling System (SASS) and in the east inlet duct using the Andersen High Capacity Sampling System (HCSS). Unit No. 2 operated at an average load of 62 MW (gross) and a coal feed rate of 48.6 short ton/hr during the sampling period.

A composite sample of the incoming coal was collected during the test period. Analysis of this sample gave the following results:

Moisture content, percent	27.2
Ash content, percent	9.03
Sulfur content, percent	1.04
Heating value, Btu/lb	7,480

Grab samples were taken at all incoming and outgoing streams and composited and these and all fly ash samples were sent to the EPA Laboratory in Las Vegas for radionuclide analysis. Since no sampling was performed at the mechanical collector inlet, the boiler bottom ash rate was taken to be 60 percent of total ash input (as suggested by plant personnel).

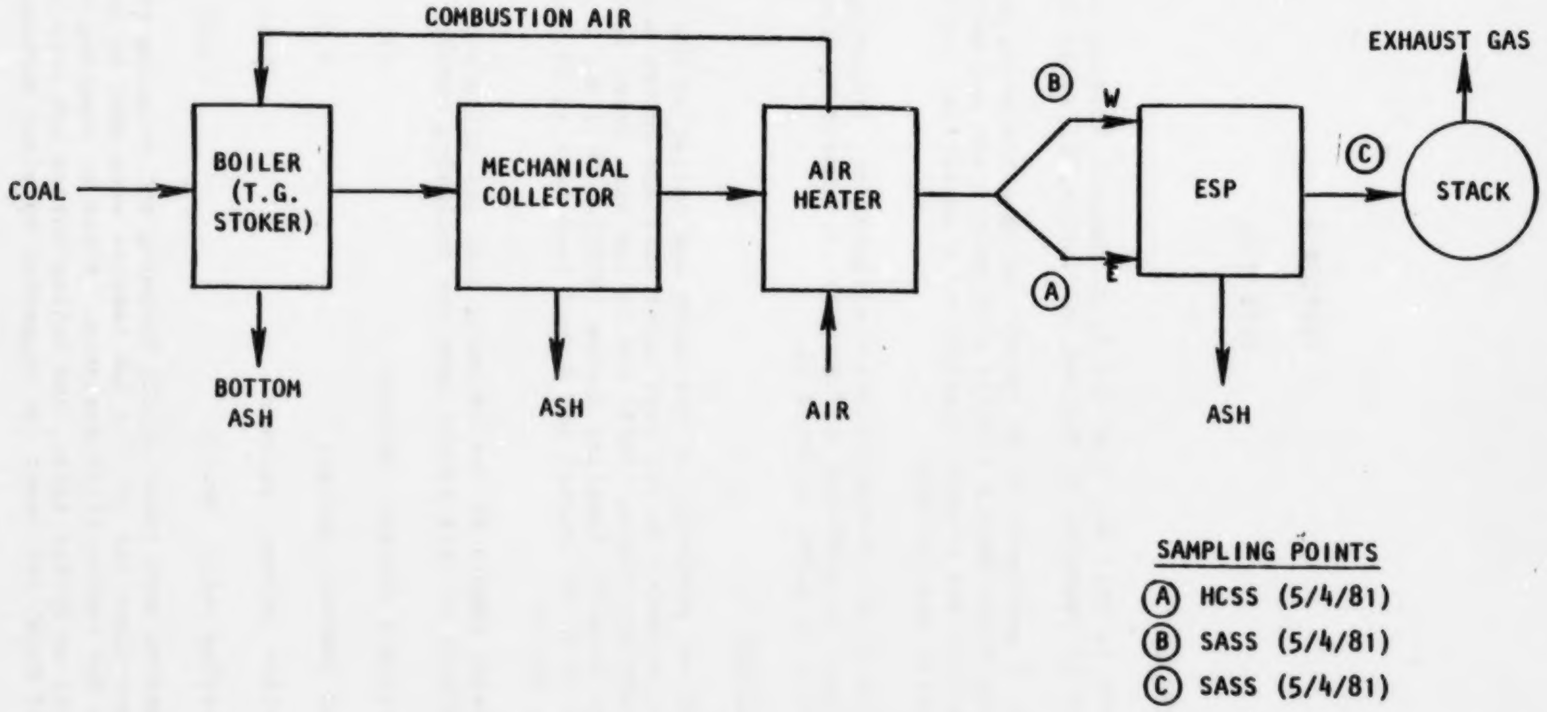

Figure 9. Plant Flow Diagram - Site M-99.

TABLE 24. DESIGN CHARACTERISTICS, SITE M-99

Boiler type	NA
Firing mode	Traveling grate stoker
Age	NA
Manufacturer	NA
Coal type	Lignite
Design coal feed rate	58.5 ton/hr
Electric generating capacity	75 mw (gross) 70 mw (net)
Particulate control	Mechanical collector and ESP
Design efficiency	MC - NA; ESP - 98.5 percent
Stack height	300 ft.
Stack diameter	13.5 ft.
Temperature	320°F
Stack velocity	42 ft/sec
Air flow rate	360,260 acfm

NA = Data not available.

RESULTS

Radionuclide balances were determined around the plant for each of the radionuclides except lead. The Las Vegas laboratory does not have the capability for Pb-210 analysis and, therefore, no values were reported for any of the samples.

All data and results for Site M-99 are presented in Appendix E. The various measured and calculated values for mass flow rates, fly ash weights, sample volumes, etc. are shown in Table E-1. Values determined by calculation (bottom ash rate, cyclone inlet ash rate and hopper discharge rate, and cyclone efficiency) are indicated by an asterisk (*); all other values are either directly or indirectly determined by measurement. Tables E-2 and E-3 show the activity values as reported by the EPA laboratory (i.e., which samples were less than background or not counted) and as used in the calculations, respectively. Table E-4 shows the individual radionuclide balance results while Table E-5 shows radionuclide rates as measured at the ESP inlet. Finally, Table E-6 presents filter and thimble (<1 μm) sample results corrected for blank radioactivity. The data presented in Appendix E are summarized in various tables and discussed in the following paragraphs.

Ash flow rates at the various points in the plant along with the associated percentage of the total ash input are shown in Table 25. As stated earlier, the boiler bottom ash rate was estimated at 60 percent of total ash input to allow for determination of cyclone inlet and cyclone hopper ash rates. Based on this assumption and the sampling conducted at the ESP inlet and outlet, the efficiency (for fly ash removal) for the mechanical collector is about 71 percent while that for the ESP is about 96 percent.

The distribution of the various radionuclides in the effluent ash streams and the percentage of total input or output is shown in Table 26. Coal is the only source of incoming material for each of the radionuclides. Most of the radionuclides are removed in the boiler bottom ash and ash removed by the cyclone, although most of the polonium was found in the ash discharged into the ESP hopper. Polonium also shows the highest fraction of any radionuclide in the fly ash released to atmosphere (5.2 percent). Most of the radium found in the output was detected in the cyclone hopper ash.

The distribution of the various radionuclides in the stack fly ash is given in Table 27 as a function of particle size. Except for polonium (most of which was found in the >10 μm fraction) most of each of the radionuclides was found in the <1 μm particle size fraction even though this fraction accounted for only 17 percent of the total fly ash collected. All radionuclides are emitted at rates less than 1 μCi/hr.

Percent closures computed for each radionuclide as part of the overall analysis are shown in Table 28. In general, the closure results are poor due to the highly variable results reported for coal activities. Whereas secular equilibrium would normally be assumed for all of the radionuclides except Th-232, the activities measured by the Las Vegas laboratory for the coal sample ranged from 0.25 to 1.5 pCi/g. The best closure was obtained for uranium (46 percent) while the worst results were found for thorium-230 (~13 percent).

TABLE 25. DISTRIBUTION OF ASH PARTICULATE, SITE M-99

Ash stream	Mass flow rate, g/hr (percent of total input)
Input from coal	4.0×10^6
Bottom ash	2.4×10^6 (60)
Cyclone inlet ash	1.6×10^6 (40)
Cyclone hopper ash	1.1×10^6 (28)
ESP inlet ash	4.5×10^5 (12)
ESP hopper ash	4.3×10^5 (11)
Fly ash	0.2×10^5 (1.0)

TABLE 26. DISTRIBUTION OF RADIONUCLIDES IN ASH, SITE M-99

Radionuclide	Radionuclide input from coal, μCi/hr (percent of total input)	Radionuclide distribution in ash, μCi/hr (percent of total output)			
		Bottom ash	Ash removed by cyclone	Ash removed by ESP	Fly ash released to atmosphere
Uranium-238	15 (100)	3.1 (46)	3.0 (43)	0.8 (11)	0.01 (0.2)
Radium-226	11 (100)	Not counted	3.6 (84)	0.7 (15)	0.02 (0.6)
Polonium-210	34 (100)	2.1 (21)	1.4 (14)	6.0 (60)	0.5 (5.2)
Lead-210	Not counted in any samples				
Thorium-230	65 (100)	4.8 (55)	3.1 (36)	0.8 (8.9)	0.01 (0.2)
Thorium-232	18 (100)	1.6 (40)	2.0 (49)	0.4 (10)	0.01 (0.3)

TABLE 27. DISTRIBUTION OF RADIONUCLIDES IN STACK FLY ASH, SITE M-99

Stack fly ash			Radionuclide emission rate, µCi/hr (percent of total emission)					
Size fraction, (µm)	Weight, (mg)	Percent of total weight	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
>10	1,447	55	0.003 (21)	0.009 (38)	0.3 (54)	--	0.002 (15)	0.002 (18)
3-10	441	17	0.0007 (5.7)	0.002 (7.9)	0.09 (18)	--	0.001 (11)	0.0006 (5.2)
1-3	312	12	0.0007 (5.3)	0.003 (12)	0.06 (12)	--	0.001 (8.6)	0.0004 (3.8)
<1	450	17	0.008 (68)	0.01 (41)	0.08 (16)	--	0.008 (66)	0.008 (73)
Total	2,650	--	0.01	0.02	0.5	--	0.01	0.01
Percent of total plant radionuclide output			(0.2)	(0.6)	(5.2)	--	(0.2)	(0.3)

TABLE 28. CLOSURE DATA FOR RADIONUCLIDE BALANCES, SITE M-99

Radionuclide balance	Percent closure--(pCi/hr out ÷ pCi/hr in)x(100)					
	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
1. Measured activities used without 2-sigma error values	45.6	39.3	28.9	--	13.2	22.5
2. Measured activities used with maximum positive 2-sigma error	45.6	39.4	29.2	--	13.1	22.6
3. Measured activities used with maximum negative 2-sigma error	45.5	39.2	28.7	--	13.2	22.5

An overall summary of the fate of each of the radionuclides is presented in Figure 10. In general, good closures are shown around the ESP, thus, indicating that the particulate sampling and radionuclide analysis was accurate. Much of the material is unaccounted for in the cyclone catch possibly due to the fact that the cyclone inlet data was determined by difference. Based on the good closures around the ESP, it is believed that the poor overall closures are due to the excessively high values reported for coal activity.

Enrichment factors computed for each radionuclide are as follows:

U-238	0.2
Ra-226	0.4
Po-210	3.0
Th-230	0.04
Th-232	0.1

Results from analysis of the impinger contents at the ESP inlet and outlet sampling locations are given below and indicate that little, if any, of the radionuclides exit to atmosphere in the vapor state. These results are discussed more fully in Section 9.

	Emission Rate, μCi/hr	
	ESP Inlet	ESP Outlet
U-238	0.03	ND
Ra-226	0.02	ND
Po-210	<0.06	ND
Pb-210	NA	NA
Th-230	0.004	ND
Th-232	0.008	ND

ND = Not detectable.

NA = No analysis.

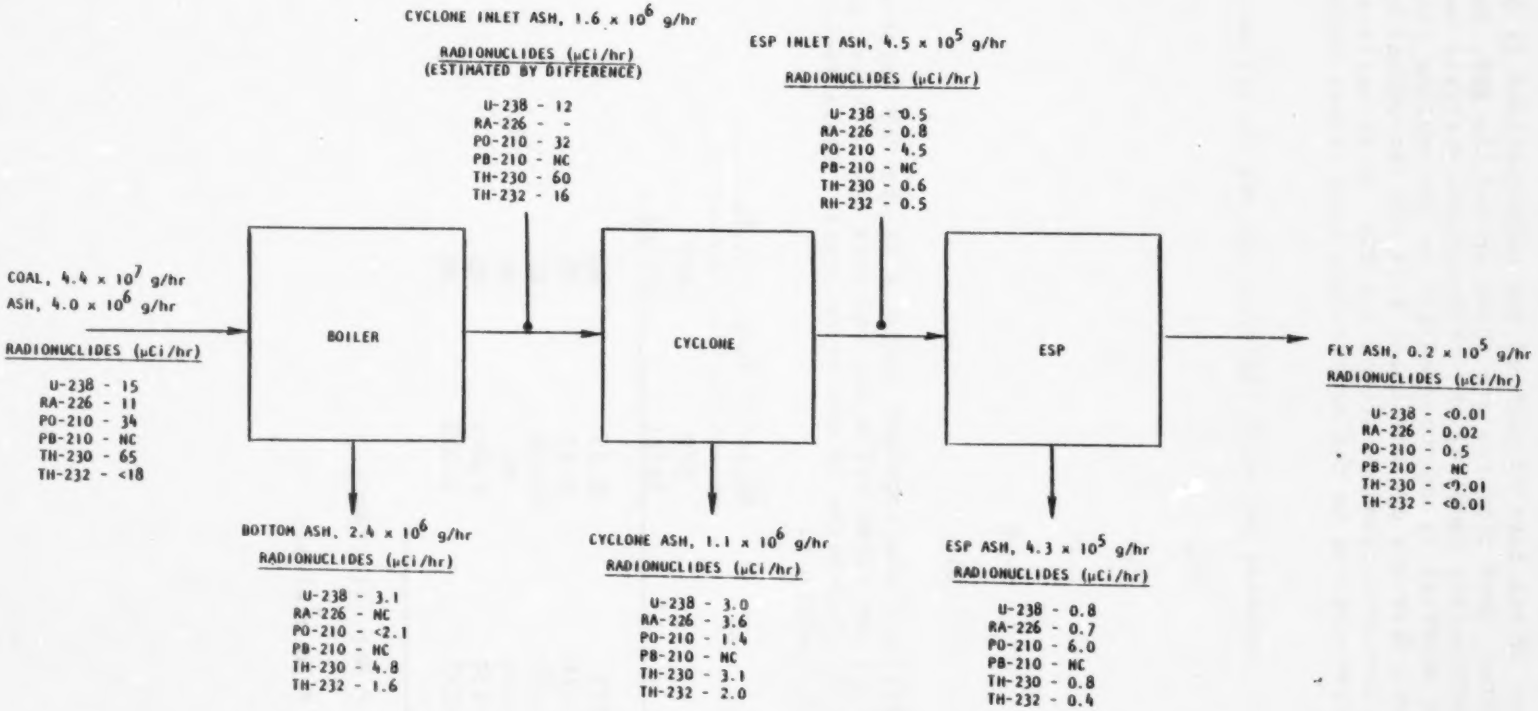

Figure 10. Radionuclide and Ash Distribution Summary, Site M-99.

SECTION 9

DISCUSSION OF RESULTS

The results of this sampling program have provided documentation of levels of radionuclide emissions to air from five coal-fired utility boilers. In general, stack emissions of the six radionuclides for which detailed assessments have been made (U-238, Ra-226, Po-210, Pb-210, Th-230, and Th-232) were small compared to the total input from the coal. On a weight basis, these emissions tended to be concentrated in the fine particle fraction (<1 μm) when compared to the weight of fly ash collected in that size range. Those radionuclides most exemplary of this phenomenon were uranium, polonium, and thorium-232 as noted below:

Site	Radionuclides Concentrated in Fine Ash
M-1	U-238, Po-210, Th-232
M-15	U-238, Po-210, Th-232
M-33	All (especially Po-210)
M-34	All (except Pb-210-not measured)
M-99	All (except Po-210)

The majority of the incoming ash and radionuclides were detected in the hopper ash of the first particulate control device following the boiler.

Radionuclide emissions expressed as a percentage of total input from the coal are shown in Table 29. With three exceptions, emissions are less than 3 percent of coal input. The exceptions are Po-210 (24 percent) and Pb-210 (8.3 percent) for Site M-1 and U-238 (6.5 percent) for Site M-15. With the exception of Site M-15, polonium represents a higher stack emission fraction than any of the other radionuclides. This is probably attributable to polonium's volatility although the exact mechanisms involved are unknown.

Annual emissions were estimated for each facility based on the hourly emission results and the assumption that the plant operates 5,694 hr/yr (65 percent load factor). These data are shown in Table 30 and indicate that Site M-1 would have the highest emissions of each of the radionuclides. This is supported by the fact that this plant burns the highest ash coal (24 percent) and had one of the lowest overall particulate removal efficiencies (98 percent). The only particulate control device at Site M-1 was a venturi scrubber (usually inefficient for collection of fine-size particles) and 80 percent of measured stack emissions were less than 1 μm. These factors coupled with the tendency of the radionuclides to condense on fine-size ash particles resulted in relatively high emissions for

TABLE 29. RADIONUCLIDE STACK EMISSIONS FOR ALL PLANTS AS A FUNCTION OF COAL INPUT

Plant	Overall particulate control efficiency (percent)	Stack emissions expressed as percent of radionuclide input from coal					
		U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
M-1	97.99	2.9	1.5	24	8.3	0.5	1.8
M-15	99.54	6.5	1.3	1.6	NC	1.0	0.4
M-33	97.16	0.5	0.5	0.9	1.2	0.5	0.5
M-34	99.97	<0.1	<0.1	<0.1	0.4	<0.1	<0.1
M-99	98.75	<0.1	0.2	1.5	NC	<0.1	<0.1

TABLE 30. SUMMARY OF ESTIMATED ANNUAL RADIONUCLIDE STACK EMISSION RATES FOR FIVE PLANTS

Facility	Coal feed rate, (short ton/hr)	Particulate control device[b] (collection efficiency)	Radionuclide emission rate, mCi/yr[a] (Enrichment Factor)[c]					
			U-238	RA-226	Po-210	Pb-210	Th-230	Th-232
M-1	340	VS-- (98.0)	120 (3.9)	63 (2.0)	996 (32.4)	342 (11.2)	17 (0.6)	8.5 (2.4)
M-15	34	MC-- (67.0) VS-- (98.6)	2.3 (2,4)	0.5 (5.2)	0.6 (8.6)	NC	0.3 (3.7)	0.1 (1.7)
M-33	433	ESP--(97.2)	14 (0.6)	13 (0.6)	22 (0.9)	30 (1.2)	12 (0.5)	8 (0.5)
M-34	646	ESP--(99.9) VS-- (74.4)	1.3 (1.2)	2.9 (2.5)	2.9 (2.5)	24 (22)	1.2 (1.1)	1.1 (1.5)
M-99	49	MC-- (71.5) ESP--(95.6)	0.06 (0.2)	0.1 (0.4)	2.8 (3.0)	NC	0.06 (0.04)	0.06 (0.1)

[a] Calculated by assuming the plant operates 5,694 hr/yr (65 percent load factor).

[b] VS = venturi scrubber; MC = mechanical collector; ESP = electrostatic precipitator.

[c] Enrichment factor = pCi/g in fly ash ÷ pCi/g in coal ash.

Site M-1. Site M-1 was also the only plant sampled which used a cyclone-fired boiler, although it is unknown what impact this would have on radionuclide emissions.

At a load factor of 65 percent, the second-highest annual radionuclide emissions would occur at Site M-33 which had the lowest overall particulate control efficiency (97 percent). However, on a percentage basis these emissions were generally less than 1 percent of total input from the coal. Emissions at this plant would probably have been higher were it not for the fact that emissions less than 1 m represented only 2 percent of total stack emissions (the lowest of any of the five sites).

The lowest estimated annual emissions were found for Sites M-99 and M-15. These two sites had the lowest coal feed rates and lowest ash content coals. In addition, they had high particulate collection efficiencies and low (compared to Site M-1) emissions of particulate matter less than 1 m in diameter.

The concentration of radionuclides in fly ash (pCi/g) as a function of particle size was investigated. Radionuclide concentration generally increases as the particle size decreases as an examination of Tables A-3, B-3, C-3, D-3, and E-3 in the appendices shows. Not all radionuclides exhibit this to the same degree, however. Polonium-210 and lead-210 show the greatest increase followed by uranium-238, radium-226, and thorium-230, 232 in decreasing order. This trend was not the same at all five boilers. It is probably influenced by boiler design and perhaps by the type of control device. At least 50 percent of the radionuclide emissions were concentrated on particles of less than 10 μm for all of the sites which were studied.

Enrichment factors (the ratio of radionuclide concentration in fly ash to its concentration in coal ash) which were computed from the measurement data are also shown in Table 30. Although these data are quite variable, they do consistently show that polonium and lead are enriched in the stack fly ash much more so than any of the other radionuclides. Some degree of enrichment was noted for practically all radionuclides measured at Sites M-1 and M-15. However, this was not the case for Th-230 at site M-1. Further, no conclusion can be drawn for lead at site M-15 because it was not measured. The remaining sites showed little or no enrichment for radionuclides other than polonium and lead.

The results of the impinger sampling conducted at all sites are shown in Table 31. Particulate control devices at the M-15 unit consist of a mechanical collector followed by a scrubber. The results shown for the inlet of this unit is that for the mechanical collector since this is the sampling location closest to the furnace and therefore the sampling point most likely to have radionuclides in the impinger samples. The M-34 unit has an ESP followed by a scrubber, but only inlet and outlet of the scrubber were sampled.

Inlet impinger samples contain some radionuclides; this is especially evident for Site M-1. It is somewhat surprising that thorium was found in these samples since it is considered to be nonvolatile. Perhaps some fine

TABLE 31. IMPINGER SAMPLING RESULTS FOR FIVE PLANTS

	Radionuclide Emission Rate, μCi/hr[a]					
Site/Sampling Location	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
M-1						
Scrubber inlets	4	1	3	20	0.3	0.08
Scrubber outlet	0.08[b]	ND	ND	ND	ND	ND
M-15						
Mech. Coll. inlet	ND	ND	ND	NA	0.02	ND
Scrubber outlet	ND	ND	ND	NA	0.01[c]	ND
M-33						
ESP inlets	0.1	ND	0.3	ND	ND	ND
ESP outlet	ND	ND	ND	ND	ND	ND
M-34						
Scrubber inlet	ND	ND	0.4	ND	ND	ND
Scrubber outlet	9[d]	ND	ND	ND	ND	ND
M-99						
ESP inlets	0.03	0.02	<0.06	NA	0.004	0.008
ESP outlet	ND	ND	ND	NA	ND	ND

[a] ND = not detectable.
NA = no analysis.

[b] This value is based on an analytical result of a sample having a 50 percent counting error. This, in addition to the absence of other radionuclides in the impingers, makes this value suspect.

[c] This result is based on the analysis of the sample collected in the second impinger. Since no Th-230 was found in the first impinger, through which the sampled stack gases flow before passing through the second impinger, the value is very doubtful.

[d] Since this result is higher than the total amount of U-238 measured in the entire scrubber inlet by a factor of about 6.0, it is obviously incorrect. It is based on an analytical result which is very high and is probably due to some contamination. No U-238 would be expected to be in the impinger since none was found in the inlet impinger samples.

particles were carried over from the sample train filter. The outlet impinger samples contain no detectable radionuclides except for a few samples where the results are highly suspect for the reasons stated in the table footnotes. It would be reasonable to conclude, therefore, that no radionuclides are present in the impinger samples collected at the outlet of the control devices of any of the boilers.

The impinger results show that at the inlets to control devices closest to the furnace a small fraction of the radionuclide output is either in the gaseous state or associated with very fine particles. There is firm evidence, however, that only very small amounts of the radionuclides will be in the gaseous state at the outlet of the control devices located farthest from the furnace. If the radioactivity in the impinger blank is used as the minimum detectable concentration, then this represents the maximum amount that could be in the gaseous state. Based on this assumption, the data below show the microcuries per hour of polonium-210 that could be in the gaseous state and released to the atmosphere from the five boilers:

Unit	M-1	M-33	M-15	M-34	M-99
$\mu Ci\,^{210}Po/h$	<0.2	<0.2	<0.02	<0.3	<0.01
% of input	<0.03	<0.05	<0.3	<0.03	<0.02

These values represent only a very small percent of the polonium-210 available as a result of burning the coal.

Several additional points are worth noting. Measured coal activitiy data are most important with respect to determining percent closure for a given radionuclide. Since results should be judged (in part) on the basis of percent closure, coal measurements are extremely important because the coal accounts for 90 percent or more of the total radionuclide input to each plant. This is all the more important considering that the fly ash rates are so small in comparison and that the activity in the fly ash emission stream is the issue of interest in this study. Coal activity data reported for nine of the sampled facilities are shown in Table 32. Coal samples from Sites M-15 and M-99 (both analyzed at EPA's Las Vegas Facility) showed the most variability with regard to radionuclide activities in the uranium and thorium decay series. For example, coal activities for Site M-99 ranged from 0.25 to 1.5 pCi/g for uranium series radionuclides whereas the values would normally be expected to be similar because of secular equilibrium. Accordingly, closure data for Site M-99 (indicated previously in Table 28) were extremely low (13 to 46 percent). Site M-15, for which three sets of coal activity data were available, showed both low and variable results. As noted previously in Section 5, an average of these data for Site M-15 was used in computing the results.

Also, actual sample volumes obtained were not always as large as desirable (shown previously in Table 3). For each site, a calculation was made prior to sampling to determine the approximate sample volume that would be required to yield enough ash particulate for reliable determination of radionuclide concentration. As indicated in Table 3, actual sample volumes at

TABLE 32. REPORTED COAL ACTIVITIES FOR NINE SAMPLING SITES

Site	Coal type	EPA Lab[a] performing analysis	Reported coal activity, pCi/g[b]					
			U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
M-1	Subbituminous	EERF	2.325	NC	NC	NC	2.14	0.265
M-15	Lignite	LVF	0.110 <0.118 0.078	NC	0.438 0.127 0.084	NC	0.711 0.072 0.055	0.427 0.055 0.046
M-33	Lignite	EERF	1.12	NC	NC	NC	1.0	0.719
M-34	Lignite	EERF	1.66	NC	NC	NC	1.59	1.11
M-99	Lignite	LVF	0.342	0.249	0.779	NC	1.48	0.399
M-16	Subbituminous	EERF	0.65	0.85	B	NC	0.32	0.15
M-18	Bituminous	EERF	0.52	1.80	0.68	NC	0.60	0.40
M-19	Bituminous	EERF	B	0.98	0.70	NC	0.75	0.40
M-98	Lignite	LVF	0.27	NC	0.33	NC	0.34	0.18

[a] U.S. EPA, Office of Radiation Programs
Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama
Las Vegas Facility (LVF), Las Vegas, Nevada

[b] B = less than background, NC = not counted.

outlet sampling locations were much lower than desired at Sites M-1 and M-34. Since a relatively large amount of fly ash was collected at Site M-1, the data for this site are believed to be valid. The results for Site M-34, however, are subject to question because of the low sample volume and the numerous sampling, equipment, and weather problems encountered.

REFERENCES

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2. Kocher, D. C. Nuclear Decay Data for Radionuclides Occurring in Routine Releases From Nuclear Fuel Cycle Facilities. Prepared for the Nuclear Regulatory Commission by the Oak Ridge National Laboratory, August 1977, pp. 13-15.

3. Shapiro, J. Radiation Protection. Harvard University Press, Cambridge, Massachusetts. 1972. p. 115

APPENDIX A

APPLE III OUTPUT AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, SITE M-1

TABLE A-1. SITE M-1 INPUT DATA (MEASURED AND CALCULATED)

DCR,G/HR	DESIGN COAL FEED RATE	3.9534E8
LF,f	LOAD FACTOR, FRACTION	.782
ACR,G/HR	ACTUAL COAL FEED RATE	3.0916E8
CAC,f	COAL ASH CONTENT, FRACTION	.242
AIN,G/HR	ASH INPUT	74815713
LFR,G/HR*	LIMESTONE FEED RATE	72742551
SMW,L/HR*	SCRUBBER MAKEUP WATER	34068
SSR,L/HR*	SCRUBBER SLUDGE RATE/LIQUID	1021220
SSR,G/HR*	SCRUBBER SLUDGE RATE/SOLID	1.3308E8
FA,G	FLY ASH SCRUBBER INLET NORTH TOTAL	27.06752
FA,G	FLY ASH SCRUBBER INLET SOUTH TOTAL	24.40419
FA,G	FLY ASH SCRUBBER OUTLET NORTH TOTAL	3.10279
FA,G	FLY ASH SCRUBBER OUTLET SOUTH TOTAL	3.41096
TVS,DSCF	TOTAL VOLUME SAMPLED SCRUBBER INLET N	181.06
TVS,DSCF	TOTAL VOLUME SAMPLED SCRUBBER INLET S	149.074
TVS,DSCF	TOTAL VOLUME SAMPLED SCRUBBER OUTLET N	729.968
TVS,DSCF	TOTAL VOLUME SAMPLED SCRUBBER OUTLET S	724.4
TF,DSCFM	TOTAL FLOW SCRUBBER INLET N	1429545
TF,DSCFM	TOTAL FLOW SCRUBBER INLET S	1537016
TF,DSCFM	TOTAL FLOW SCRUBBER OUTLET N	790483
TF,DSCFM	TOTAL FLOW SCRUBBER OUTLET S	1274247
CONSTANT	SCRUBBER INLET NORTH	473725.3
CONSTANT	SCRUBBER INLET SOUTH	618625.4
CONSTANT	SCRUBBER OUTLET NORTH	64974.05
CONSTANT	SCRUBBER OUTLET NORTH	105542.3
FAR,G/HR	FLY ASH RATE SCRUBBER INLET NORTH	12822569
FAR,G/HR	FLY ASH RATE SCRUBBER INLET SOUTH	15097051
FAR,G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH	201600.8
FAR,G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH	360000.5
FAR,G/HR	TOTAL FLY ASH RATE SCRUBBER INLET	27919620
FAR,G/HR	TOTAL FLY ASH RATE SCRUBBER OUTLET	561601.3
SAR,G/HR	SCRUBBER ASH RATE	27358019
VSEFF, %	VENTURI SCRUBBER EFFICIENCY (PARTICULATE)	97.98851
BAR,G/HR	BOTTOM ASH RATE	46896094
FA,G	FLY ASH SCRUBBER OUTLET NORTH, GT 10 U	.32854
FA,G	FLY ASH SCRUBBER OUTLET NORTH, GT 10 U PROBE RINSE	.14541
FA,G	FLY ASH SCRUBBER OUTLET NORTH, 3-10 U	.00038
FA,G	FLY ASH SCRUBBER OUTLET NORTH, 1-3 U	.03087
FA,G	FLY ASH SCRUBBER OUTLET NORTH, LT 1 U	2.59759

TABLE A-1. (CONT'D)

FA, G	FLY ASH SCRUBBER OUTLET SOUTH, GT 10 U	.81128
FA, G	FLY ASH SCRUBBER OUTLET SOUTH, GT 10 U PROBE RINSE	.03419
FA, G	FLY ASH SCRUBBER OUTLET SOUTH, 3-10 U	.01414
FA, G	FLY ASH SCRUBBER OUTLET SOUTH, 1-3 U	.03886
FA, G	FLY ASH SCRUBBER OUTLET SOUTH, LT 1 U	2.51249
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH, GT 10 U	21346.58
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH, GT 10 U PROBE RINSE	9447.877
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH, 3-10 U	24.69014
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH, 1-3 U	2005.749
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET NORTH, LT 1 U	168776.0
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH, GT 10 U	85624.33
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH, GT 10 U PROBE RINSE	3608.490
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH, 3-10 U	1492.368
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH, 1-3 U	4101.373
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET SOUTH, LT 1 U	265173.9

FA, G	FLY ASH INLET N & S PRECUTTER GT 10 U	43.40216
FA, G	FLY ASH INLET N & S 1ST STAGE GT 10 U	.42654
FA, G	FLY ASH INLET N & S 2ND STAGE 3-10 U	2.03872
FA, G	FLY ASH INLET N & S 3RD STAGE 1-3 U	2.3316
FA, G	FLY ASH INLET N & S THIMBLES LT 1 U	2.61053
FA, G	FLY ASH INLET NORTH IMP. RINSE GT 10 U	.16608
FA, G	FLY ASH INLET NORTH PRB. RINSE GT 10 U	.30331
FA, G	FLY ASH INLET SOUTH IMP. RINSE GT 10 U	.10174
FA, G	FLY ASH INLET SOUTH PRB. RINSE GT 10 U	.02261
FA, G	FLY ASH INLET SOUTH UMB. RINSE GT 10 U	.06842
FAR, G/HR	FLY ASH RATE INLET N & S PRECUTTER GT 10 U	23603548
FAR, G/HR	FLY ASH RATE INLET N & S 1ST STAGE GT 10 U	235098.6
FAR, G/HR	FLY ASH RATE INLET N & S 2ND STAGE 3-10 U	1083575.
FAR, G/HR	FLY ASH RATE INLET N & S 3RD STAGE 1-3 U	1261173.
FAR, G/HR	FLY ASH RATE INLET N & S THIMBLES LT 1 U	1394611.
FAR, G/HR	FLY ASH RATE INLET NORTH IMP. RINSE GT 10 U	78676.30
FAR, G/HR	FLY ASH RATE INLET NORTH PRB. RINSE GT 10 U	143685.6
FAR, G/HR	FLY ASH RATE INLET SOUTH IMP. RINSE GT 10 U	62938.95
FAR, G/HR	FLY ASH RATE INLET SOUTH PRB. RINSE GT 10 U	13987.12
FAR, G/HR	FLY ASH RATE INLET SOUTH UMB. RINSE GT 10 U	42326.35

TABLE A-2. ACTIVITY DATA AS REPORTED BY EPA LABORATORY

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	2.325	NC	NC	NC	2.14	.265
E	.1082				.0694	.1881
LIMESTONE	1.433	NC	NC	NC	1.176	.08066
E	.1211				.1417	.4648
SCR WATER(D) pCi/L	2.178	.36	NC	NC	.0303	B
E	.1249	.06			.8589	
SCR WATER(U) pCi/L	.1299	.11	NC	NC	.09472	.01684
E	.2735	.14			.3154	.7922
BOTTOM ASH	6.24	3.75	NC	1.414	5.57	1.093
E	.1147	.02		.6025	.1033	.181
SSL/D pCi/L	2.42	NC	NC	NC	.02594	.0173
E	.1411				.8188	1.226
SSL/U pCi/L	.2228	NC	NC	NC	.1325	.01718
E	.2253				.2823	.8591
SSS	3.096	NC	NC	NC	2.675	.3381
E	.1024				.1158	.2626
FAON GT 10 U PR	14.27	NC	9.98	NC	2.3	.343
E	.1228		.2653		.2207	.0341
FAOC GT 10 U	18.79	16.59	238.7	122.8	6.25	.727
E	.1176	.04	.1241	.4102	.1825	.6401
FAOC 3-10 U	16.05	22.04	0	729.3	7.62	1.38
E	.4163	.17	.2637	3.58	.7045	2
FAOC 1-3 U	29.66	29.26	144	101.4	12.04	1.96
E	.1544	.05	.1695	.822	.2106	.5819
FAOS GT 10 U PR	20.92	NC	147	NC	2.75	.369
E	.0993		.1384		.1208	.3177
FAOS LT 1 U	40.68	20.26	370.2	155.5	5.08	3.65
E	.0986	.02	.1344	.1072	.1164	.1359
FAON LT 1 U	45.77	19.71	294.1	25.27	4.93	2.54
E	.1113	.02	.1355	.1441	.1187	.1628
FAIC GT 10 U PR	9.707	.06	11.21	25.608	9.304	1.278
E	.1122	.11	.1491	.1303	.0372	.0621
FAIC GT 10 U	17.53	13.46	191.8	159	14.6	1.22
E	.1227	.03	.1727	.6519	.1116	.0498
FAIC 3-10 U	19.35	16.9	NC	54.86	11	1.08
E	.0958	.01		.1499	.0578	.1147
FAIC 1-3 U	24.1	16.22	58.8	77.2	24.1	2.37
E	.1026	.01	.1664	.1324	.0563	.0914
FAIC LT 1 U	31.07	43.5	195.4	75.4	4.15	.72
E	.1142	.006	.1104	.1565	.0804	.1818
FAIN GT 10 U IR	16.66	NC	93.8	NC	16.2	1.61
E	.1609		.1738		.1193	.3723
FAIN GT 10 U PR	6.05	NC	29.8	NC	4.85	.426
E	.1831		.1975		.1455	.5221
FAIS GT 10 U IR	2.9	NC	29.7	NC	2.65	1.04
E	.3442		.2651		.3799	.6568
FAIS GT 10 U PR	3.6	NC	54.3	NC	4.91	B
E	.7129		.3618		.5783	
FAIS GT 10 U UR	2.74	NC	24.4	NC	1.39	.38
E	.4777		.3538		.7932	1.491

NOTE: NC = NOT COUNTED
B = LESS THAN BACKROUND

TABLE A-3. ACTIVITY DATA AS USED IN CALCULATIONS

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	2.325	2.325	2.325	2.325	2.14	.265
E	.1082	.1082	.1082	.1082	.0694	.1881
LIMESTONE	1.433	1.433	1.433	1.433	1.176	.08066
E	.1211	.1211	.1211	.1211	.1417	.4648
SCR WATER(D) pCi/L	2.178	.36	0	0	.0303	0
E	.1249	.06	0	0	.8589	.1249
SCR WATER(U) pCi/L	.1299	.11	0	0	.09472	.01684
E	.2735	.14	0	0	.3154	.7922
BOTTOM ASH	6.24	3.75	0	1.414	5.57	1.093
E	.1147	.02	.3537	.6025	.1033	.181
SSL/D pCi/L	2.42	0	0	0	.02594	.0173
E	.1411	0	0	0	.8188	1.226
SSL/U pCi/L	.2228	0	0	0	.1325	.01718
E	.2253	0	0	0	.2823	.8591
SSS	3.096	1.48	4.52	7.12	2.675	.3381
E	.1024	0	0	0	.1158	.2626
FAON GT 10 U PR	14.27	0	9.98	0	2.3	.343
E	.1228	0	.2653	0	.2207	.0341
FAOC GT 10 U	18.79	16.59	238.7	122.8	6.25	.727
E	.1176	.04	.1241	.4102	.1825	.6401
FAOC 3-10 U	16.05	22.04	0	729.3	7.62	1.38
E	.4163	.17	.2637	2.58	.7045	2
FAOC 1-3 U	29.66	29.26	144	101.4	12.04	1.96
E	.1544	.05	.1695	.822	.2106	.5819
FAOS GT 10 U PR	20.92	0	147	0	2.75	.369
E	.0993	0	.1384	0	.1208	.3177
FAOS LT 1 U	40.68	20.26	370.2	155.5	5.08	3.65
E	.0986	.02	.1344	.1072	.1164	.1359
FAON LT 1 U	45.77	19.71	294.1	25.27	4.93	2.54
E	.1113	.02	.1355	.1441	.1187	.1628
FAIC GT 10 U PR	9.707	.06	11.21	25.608	9.304	1.278
E	.1122	.11	.1491	.1303	.0372	.0621
FAIC GT 10 U	17.53	13.46	191.8	159	14.6	1.22
E	.1227	.03	.1727	.6519	.1116	.0498
FAIC 3-10 U	19.35	16.9	0	54.86	11	1.08
E	.0958	.01	0	.1499	.0578	.1147
FAIC 1-3 U	24.1	16.22	58.8	77.2	24.1	2.37
E	.1026	.01	.1664	.1324	.0563	.0914
FAIC LT 1 U	31.07	43.5	195.4	75.4	4.15	.72
E	.1142	.006	.1104	.1565	.0804	.1818
FAIN GT 10 U IR	16.66	0	93.8	0	16.2	1.61
E	.1609	0	.1738	0	.1193	.3723
FAIN GT 10 U PR	6.05	0	29.8	0	4.85	.426
E	.1831	0	.1975	0	.1455	.5221
FAIS GT 10 U IR	2.9	0	29.7	0	2.65	1.04
E	.3442	0	.2651	0	.3799	.6568
FAIS GT 10 U PR	3.6	0	54.3	0	4.91	0
E	.7129	0	.3618	0	.5783	0
FAIS GT 10 U UR	2.74	0	24.4	0	1.39	.38
E	.4777	0	.3538	0	.7932	1.491

TABLE A-4. RADIONUCLIDE BALANCE RESULTS

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
U-238 IN COAL	7.1879E8	87.33
U-238 IN LIMESTONE	1.0424E8	
U-238 IN SCRUBBER WATER	78625.54	
U-238 IN TOTAL	8.2311E8	
U-238 OUT BOTTOM ASH	2.9263E8	40.18
U-238 OUT SCRUBBER SLUDGE (LIQUID)	2698880.	0.37
U-238 OUT SCRUBBER SLUDGE (SOLID)	4.1202E8	56.57
U-238 OUT FLY ASH NORTH OUTLET GT 10 U PR	134821.2	
U-238 OUT FLY ASH SOUTH OUTLET GT 10 U PR	75489.61	
U-238 OUT FLY ASH OUTLET COMPOSITE GT 10 U	2009983.	
U-238 OUT FLY ASH OUTLET GT 10 U TOTAL	2220294.	0.30
U-238 OUT FLY ASH OUTLET COMPOSITE 3-10 U	24348.78	0.00
U-238 OUT FLY ASH OUTLET COMPOSITE 1-3 U	181137.2	0.02
U-238 OUT FLY ASH SOUTH OUTLET LT 1 U	10787274	
U-238 OUT FLY ASH NORTH OUTLET LT 1 U	7724875.	
U-238 OUT FLY ASH OUTLET LT 1 U	18512149	2.54
U-238 OUT FLY ASH TOTAL	20937930	2.87
U-238 OUT TOTAL	7.2828E8	
OUT/IN, %	88.48	
RA226 IN COAL	7.1879E8	87.33
RA226 IN LIMESTONE	1.0424E8	
RA226 IN SCRUBBER WATER	16011.96	
RA226 IN TOTAL	8.2304E8	
RA226 OUT BOTTOM ASH	1.7586E8	45.86
RA226 OUT SCRUBBER SLUDGE (LIQUID)	0	0.00
RA226 OUT SCRUBBER SLUDGE (SOLID)	1.9696E8	51.36
RA226 OUT FLY ASH NORTH OUTLET GT 10 U PR	0	
RA226 OUT FLY ASH SOUTH OUTLET GT 10 U PR	0	
RA226 OUT FLY ASH OUTLET COMPOSITE GT 10 U	1774647.	
RA226 OUT FLY ASH OUTLET GT 10 U TOTAL	1774647.	0.46
RA226 OUT FLY ASH OUTLET COMPOSITE 3-10 U	33435.95	0.01
RA226 OUT FLY ASH OUTLET COMPOSITE 1-3 U	178694.4	0.05
RA226 OUT FLY ASH SOUTH OUTLET LT 1 U	5372423.	
RA226 OUT FLY ASH NORTH OUTLET LT 1 U	3326574.	
RA226 OUT FLY ASH OUTLET LT 1 U	8698997.	2.27
RA226 OUT FLY ASH TOTAL	10685775	2.79
RA226 OUT TOTAL	3.8350E8	
OUT/IN, %	46.60	

TABLE A-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
PO210 IN COAL	7.1879E8	87.33
PO210 IN LIMESTONE	1.0424E8	
PO210 IN SCRUBBER WATER	0	
PO210 IN TOTAL	8.2303E8	
PO210 OUT BOTTOM ASH	0	0.00
PO210 OUT SCRUBBER SLUDGE (LIQUID)	0	0.00
PO210 OUT SCRUBBER SLUDGE (SOLID)	6.0152E8	77.48
PO210 OUT FLY ASH NORTH OUTLET GT 10 U PR	94289.81	
PO210 OUT FLY ASH SOUTH OUTLET GT 10 U PR	530448.1	
PO210 OUT FLY ASH OUTLET COMPOSITE GT 10 U	25533956	
PO210 OUT FLY ASH OUTLET GT 10 U TOTAL	26158694	3.37
PO210 OUT FLY ASH OUTLET COMPOSITE 3-10 U	0	0.00
PO210 OUT FLY ASH OUTLET COMPOSITE 1-3 U	879425.5	0.11
PO210 OUT FLY ASH SOUTH OUTLET LT 1 U	98167377	
PO210 OUT FLY ASH NORTH OUTLET LT 1 U	49637007	
PO210 OUT FLY ASH OUTLET LT 1 U	1.4780E8	19.04
PO210 OUT FLY ASH TOTAL	1.7484E8	22.52
PO210 OUT TOTAL	7.7636E8	
OUT/IN, %	94.33	
PB210 IN COAL	7.1879E8	87.33
PB210 IN LIMESTONE	1.0424E8	
PB210 IN SCRUBBER WATER	0	
PB210 IN TOTAL	8.2303E8	
PB210 OUT BOTTOM ASH	66311076	6.17
PB210 OUT SCRUBBER SLUDGE (LIQUID)	0	0.00
PB210 OUT SCRUBBER SLUDGE (SOLID)	9.4753E8	88.21
PB210 OUT FLY ASH NORTH OUTLET GT 10 U PR	0	
PB210 OUT FLY ASH SOUTH OUTLET GT 10 U PR	0	
PB210 OUT FLY ASH OUTLET COMPOSITE GT 10 U	13136027	
PB210 OUT FLY ASH OUTLET GT 10 U TOTAL	13136027	1.22
PB210 OUT FLY ASH OUTLET COMPOSITE 3-10 U	1106390.	0.10
PB210 OUT FLY ASH OUTLET COMPOSITE 1-3 U	619262.1	0.06
PB210 OUT FLY ASH SOUTH OUTLET LT 1 U	41234541	
PB210 OUT FLY ASH NORTH OUTLET LT 1 U	4264968.	
PB210 OUT FLY ASH OUTLET LT 1 U	45499509	4.24
PB210 OUT FLY ASH TOTAL	60361189	5.62
PB210 OUT TOTAL	1.0742E9	
OUT/IN, %	130.52	

TABLE A-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
TH230 IN COAL	6.6159E8	88.55
TH230 IN LIMESTONE	85545240	
TH230 IN SCRUBBER WATER	4259.181	
TH230 IN TOTAL	7.4714E8	
TH230 OUT BOTTOM ASH	2.6121E8	42.11
TH230 OUT SCRUBBER SLUDGE (LIQUID)	161802.1	0.03
TH230 OUT SCRUBBER SLUDGE (SOLID)	3.5599E8	57.39
TH230 OUT FLY ASH NORTH OUTLET GT 10 U PR	21730.12	
TH230 OUT FLY ASH SOUTH OUTLET GT 10 U PR	9923.348	
TH230 OUT FLY ASH OUTLET COMPOSITE GT 10 U	668568.2	
TH230 OUT FLY ASH OUTLET GT 10 U TOTAL	700221.6	0.11
TH230 OUT FLY ASH OUTLET COMPOSITE 3-10 U	11559.98	0.00
TH230 OUT FLY ASH OUTLET COMPOSITE 1-3 U	73529.74	0.01
TH230 OUT FLY ASH SOUTH OUTLET LT 1 U	1347083.	
TH230 OUT FLY ASH NORTH OUTLET LT 1 U	832065.4	
TH230 OUT FLY ASH OUTLET LT 1 U	2179149.	0.35
TH230 OUT FLY ASH TOTAL	2964460.	0.48
TH230 OUT TOTAL	6.2033E8	
OUT/IN, %	83.03	
TH232 IN COAL	81926298	93.32
TH232 IN LIMESTONE	5867414.	
TH232 IN SCRUBBER WATER	573.7051	
TH232 IN TOTAL	87794286	
TH232 OUT BOTTOM ASH	51257430	52.42
TH232 OUT SCRUBBER SLUDGE (LIQUID)	35211.67	0.04
TH232 OUT SCRUBBER SLUDGE (SOLID)	44994348	46.02
TH232 OUT FLY ASH NORTH OUTLET GT 10 U PR	3240.622	
TH232 OUT FLY ASH SOUTH OUTLET GT 10 U PR	1331.533	
TH232 OUT FLY ASH OUTLET COMPOSITE GT 10 U	77767.85	
TH232 OUT FLY ASH OUTLET GT 10 U TOTAL	82340.00	0.08
TH232 OUT FLY ASH OUTLET COMPOSITE 3-10 U	2093.540	0.00
TH232 OUT FLY ASH OUTLET COMPOSITE 1-3 U	11969.96	0.01
TH232 OUT FLY ASH SOUTH OUTLET LT 1 U	967884.7	
TH232 OUT FLY ASH NORTH OUTLET LT 1 U	428690.9	
TH232 OUT FLY ASH OUTLET LT 1 U	1396576.	1.43
TH232 OUT FLY ASH TOTAL	1492979.	1.53
TH232 OUT TOTAL	97779969	
OUT/IN, %	111.37	

TABLE A-5. RESULTS OF TH-230 BALANCE AROUND SCRUBBER

RADIONUCLIDE/STREAM DESCRIPTION		pCi/hr or pCi/G
TH-230 SCRUBBER INLET		2.7341E8
TH-230 SCRUBBER SLUDGE		3.5599E8
SCRUBBER SLUDGE RATE, G/HR		1.3308E8
RA-226 SCRUBBER INLET		1.0401E8
RA-226 SCRUBBER SLUDGE		1.9759E8
RA-226 SCRUBBER SLUDGE ACTIVITY	pCi/G	1.484710
PO-210 SCRUBBER INLET		6.7167E8
PO-210 SCRUBBER SLUDGE		6.0107E8
PO-210 SCRUBBER SLUDGE ACTIVITY	pCi/G	4.516625
PB-210 SCRUBBER INLET		9.0378E8
PB-210 SCRUBBER SLUDGE		9.4766E8
PB-210 SCRUBBER SLUDGE ACTIVITY	pCi/G	7.120983
U-238 SCRUBBER INLET		3.3046E8
U-238 SCRUBBER SLUDGE		4.1384E8
TH-232 SCRUBBER INLET		35884936
TH-232 SCRUBBER SLUDGE		40259944

TABLE A-6. ANALYTICAL DATA AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY

	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
(1) ANALYTICAL DATA--						
HCSS thimbles pCi/2 thimbles	0.3 ± 36%	0.6 ± 17%	1.1 ± 46%	4.0 ± 233%	0.3 ± 32%	0.5 ± 25%
SASS filters pCi/2 filters	1.4 ± 18%	2.1 ± 5%	1.1 ± 30%	7.0 ± 77%	1.6 ± 14%	1.9 ± 13%
0.1 HNO_3, pCi/l	0.4 ± 67%	5.8 ± 11%	0.5 ± 96%	36 ± 36%	0.7 ± 70%	-0.05 ± 200%
Water (DDI), pCi/l	0.2 ± 112%	1.5 ± 19%	0.4 ± 85%	8 ± 161%	2 ± 39%	0.6 ± 67%
(2) FILTER AND THIMBLE (<1 μm) SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, μCi/hr--						
North and South inlets (5 thimbles)	41	63	280	110	5.8	0.3
North outlet (4 filters)	7.4	2.8	50	2.7	0.5	ND
South outlet (8 filters)	10	4.5	98	38	0.7	0.2

ND = Not detectable.

APPENDIX B

APPLE III OUTPUT AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, SITE M-15

TABLE B-1. SITE M-15 INPUT DATA (MEASURED AND CALCULATED)

DCR, G/HR	DESIGN COAL FEED RATE	46105540
LF, f	LOAD FACTOR, FRACTION	.674
ACR, G/HR	ACTUAL COAL FEED RATE	31075134
CAC, f	COAL ASH CONTENT, FRACTION	.0914
AIN, G/HR	ASH INPUT	2840267.
FA, G	MC INLET TOTAL	14.38116
FA, G	MC OUTLET TOTAL	31.11474
FA, G	VS INLET TOTAL	54.72437
FA, G	VS OUTLET TOTAL	.78404
TVS, DSCF	TOTAL VOLUME SAMPLED MC INLET	55.296
TVS, DSCF	TOTAL VOLUME SAMPLED MC OUTLET	377.588
TVS, DSCF	TOTAL VOLUME SAMPLED VS INLET	776.62
TVS, DSCF	TOTAL VOLUME SAMPLED VS OUTLET	866.763
TF, DSCFM	TOTAL FLOW MC INLET	135403
TF, DSCFM	TOTAL FLOW MC OUTLET	141031
TF, DSCFM	TOTAL FLOW VS INLET	126003
TF, DSCFM	TOTAL FLOW VS OUTLET	132830
CONSTANT	MC INLET	146921.7
CONSTANT	MC OUTLET	22410.30
CONSTANT	VS INLET	9734.722
CONSTANT	VS OUTLET	9194.901
FAR, G/HR	FLY ASH RATE MC INLET	2112904.
FAR, G/HR	FLY ASH RATE MC OUTLET	697290.6
FAR, G/HR	FLY ASH RATE VS INLET	532726.5
FAR, G/HR	FLY ASH RATE VS OUTLET	7209.170
BAR, G/HR	BOTTOM ASH RATE	727363.4
MCAR, G/HR	MC ASH RATE	1415613.
MCEFF, %	MC EFFICIENCY	66.99847
VSAR, G/HR	VS ASH RATE	525517.4
VSEFF, %	VS EFFICIENCY	98.64674
SWR, L/HR*	SCRUBBER WATER RATE	16380
SSLR, L/HR*	SCRUBBER SPENT LIQUID RATE	3820
FA, G	OUTLET > 10 U	.04836
FA, G	OUTLET 3-10 U	.01101
FA, G	OUTLET 1-3 U	.17358
FA, G	OUTLET < 1 U - FILTER	.21001
FA, G	OUTLET >10 U - PROBE RINSE	.34108

TABLE B-1. (CONT'D)

FAR,G/HR	OUTLET GT 10 u	444.6654
FAR,G/HR	OUTLET > 10 U - PROBE RINSE	3136.197
FAR,G/HR	OUTLET 3-10 U	101.2359
FAR,G/HR	OUTLET 1-3 U	1596.051
FAR,G/HR	OUTLET < 1 U - FILTER	1931.021
FA,G	MC INLET GT 10 U	6.9429
FA,G	MC INLET GT 10 U - PROBE RINSE	2.47289
FA,G	MC INLET 3-10 U	4.52346
FA,G	MC INLET 1-3 U	.40932
FA,G	MC INLET LT 1 U	.03259
FAR,G/HR	MC INLET GT 10 U	1020062.
FAR,G/HR	MC INLET GT 10 U - PROBE RINSE	363321.1
FAR,G/HR	MC INLET 3-10 U	664594.2
FAR,G/HR	MC INLET 1-3 U	60137.97
FAR,G/HR	MC INLET LT 1 U	4788.177
FA,G	MC OUTLET GT 10 U	12.35476
FA,G	MC OUTLET GT 10 U - PROBE RINSE	.9418
FA,G	MC OUTLET 3-10 U	15.38807
FA,G	MC OUTLET 1-3 U	2.24465
FA,G	MC OUTLET LT 1 U	.18546
FAR,G/HR	MC OUTLET GT 10 U	276873.9
FAR,G/HR	MC OUTLET GT 10 U - PROBE RINSE	21106.02
FAR,G/HR	MC OUTLET 3-10 U	344851.3
FAR,G/HR	MC OUTLET 1-3 U	50303.28
FAR,G/HR	MC OUTLET LT 1 U	4156.214
FA,G	VS INLET GT 10 U	21.1595
FA,G	VS INLET GT 10 U - PROBE RINSE	2.04262
FA,G	VS INLET 3-10 U	24.17904
FA,G	VS INLET 1-3 U	7.01535
FA,G	VS INLET LT 1 U	.32786
FAR,G/HR	VS INLET GT 10 U	205981.9
FAR,G/HR	VS INLET GT 10 U - PROBE RINSE	19884.34
FAR,G/HR	VS INLET 3-10 U	235376.2
FAR,G/HR	VS INLET 1-3 U	68292.48
FAR,G/HR	VS INLET LT 1 U	3191.626

TABLE B-2. ACTIVITY DATA AS REPORTED BY EPA LABORATORY

SAMPLE DESCRIPTION	RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR					
	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	.198	NC	.198	NC	.198	.175
E	.00104		.00137		.000957	.000721
SCR WATER pCi/L	1.53	.204	.572	NC	.036	.0586
E	.00151	.00154	.00131		0	.000287
BOTTOM ASH	1.69	1.59	.738	NC	2.48	.807
E	.00322	.00218	.00298		.00571	.00329
MC ASH	2.37	2.28	.924	NC	1.61	1.83
E	.0072	.0023	.0058		.0027	.0029
VS SPENT SOLID	LOST	2.4	2.32	NC	.284	1.5
E		.0043	.00246		.000649	.00155
VS SPENT LIQ pCi/L	14.2	.671	1.42	NC	.724	.322
E	.0131	.0023	0		.00255	.00174
FLY ASH GT 10 U	5.49	23.4	19.56	NC	2.35	1.34
E	.0113	.0475	.0236		.00714	.00537
FLY ASH 3-10 U	3.01	6.86	7.84	NC	3.81	2.7
E	.0112	.0469	.0193		.0124	.0105
FLY ASH 1-3 U	4.66	5.74	11.86	NC	3.44	1.93
E	.00687	.0153	.0108		.00547	.00405
FLY ASH LT 1 U- F	9.19	10.38	25.86	NC	8.43	8.09
E	.00281	.00375	.00601		.00257	.00251
FLY ASH GT 10U-PR	3.02	12.9	17.58	NC	11	1.33
E	.00887	.0251	.0282		.0178	.00621
THE FOLLOWING DATA SETS USED WITHOUT ERROR VALUES :						
MC INLET GT 10 U	2.1	1.55	1.53	NC	2.64	1.04
MC INLET GT 10 U P	2.03	1.83	5.34	NC	1.53	2.09
MC INLET 3-10 U	2.23	1.1	3.93	NC	2.51	1.24
MC INLET 1-3 U	4.04	7.78	5.2	NC	2.7	2.28
MC INLET LT 1 U	28.32	59.22	45.73	NC	28.17	33.45
MC OUTLET GT 10 U	2.52	3.45	5.07	NC	2.7	1.11
MC OUTLETGT 10 U P	5.67	3.03	7.78	NC	4.11	1.29
MC OUTLET 3-10 U	2.84	NC	3.56	NC	1.68	1.75
MC OUTLET 1-3 U	4.24	NC	10.86	NC	3.25	1.73
MC OUTLET LT 1 U	8.68	NC	30.49	NC	4.23	6.69
VS INLET GT 10 U	2.52	3.1	2.78	NC	1.85	2.37
VS INLET GT 10 U P	2.66	3.66	5.52	NC	2.05	1.62
VS INLET 3-10 U	3.59	2.94	5.11	NC	2.12	2.63
VS INLET 1-3 U	3.4	5.56	7.38	NC	3.26	2.72
VS INLET LT 1 U	LOST	LOST	LOST	LOST	LOST	LOST

NOTE : NC = NOT COUNTED
LOST = SAMPLE LOST

TABLE B-3. ACTIVITY DATA AS USED IN CALCULATIONS

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	.198	.198	.198	.198	.198	.175
E	.00104	.00104	.00137	.00104	.000957	.000721
SCR WATER pCi/L	1.53	.204	.572	0	.036	.0586
E	.00151	.00154	.00131	0	0	.000287
BOTTOM ASH	1.69	1.59	.738	0	2.48	.807
E	.00322	.00218	.00298	0	.00571	.00329
MC ASH	2.37	2.28	.924	0	1.61	1.83
E	.0072	.0023	.0058	0	.0027	.0029
VS SPENT SOLID	0	2.4	2.32	0	.284	1.5
E	0	.0043	.00246	0	.000649	.00155
VS SPENT LIQ pCi/L	14.2	.671	1.42	0	.724	.322
E	.0131	.0023	0	0	.00255	.00174
FLY ASH GT 10 U	5.49	23.4	19.56	0	2.35	1.34
E	.0113	.0475	.0236	0	.00714	.00537
FLY ASH 3-10 U	3.01	6.86	7.84	0	3.81	2.7
E	.0112	.0469	.0193	0	.0124	.0105
FLY ASH 1-3 U	4.66	5.74	11.86	0	3.44	1.93
E	.00687	.0153	.0108	0	.00547	.00405
FLY ASH LT 1 U- F	9.19	10.38	25.86	0	8.43	8.09
E	.00281	.00375	.00601	0	.00257	.00251
FLY ASH GT 10U-PR	3.02	12.9	17.58	0	11	1.33
E	.00887	.0251	.0282	0	.0178	.00621
THE FOLLOWING DATA SETS USED WITHOUT ERROR VALUES :						
MC INLET GT 10 U	2.1	1.55	1.53	0	2.64	1.04
MC INLET GT 10 U P	2.03	1.83	5.34	0	1.53	2.09
MC INLET 3-10 U	2.23	1.1	3.93	0	2.51	1.24
MC INLET 1-3 U	4.04	7.78	5.2	0	2.7	2.28
MC INLET LT 1 U	28.32	59.22	45.73	0	28.17	33.45
MC OUTLET GT 10 U	2.52	3.45	5.07	0	2.7	1.11
MC OUTLETGT 10 U P	5.67	3.03	7.78	0	4.11	1.29
MC OUTLET 3-10 U	2.84	0	3.56	0	1.68	1.75
MC OUTLET 1-3 U	4.24	0	10.86	0	3.25	1.73
MC OUTLET LT 1 U	8.68	0	30.49	0	4.23	6.69
VS INLET GT 10 U	2.52	3.1	2.78	0	1.85	2.37
VS INLET GT 10 U P	2.66	3.66	5.52	0	2.05	1.62
VS INLET 3-10 U	3.59	2.94	5.11	0	2.12	2.63
VS INLET 1-3 U	3.4	5.56	7.38	0	3.26	2.72
VS INLET LT 1 U	0	0	0	0	0	0

TABLE B-4. RADIONUCLIDE BALANCE RESULTS

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
U-238 IN COAL	6152877.	99.59
U-238 IN SCRUBBER WATER	25061.4	
U-238 IN TOTAL	6177938.	
U-238 OUT BOTTOM ASH	1229244.	26.29
U-238 OUT MC ASH	3355003.	71.75
U-238 OUT VS SPENT SOLID	0	0.00
U-238 OUT VS SPENT LIQUID	54244	1.16
U-238 OUT FLY ASH GT 10 U	2441.213	
U-238 OUT FLY ASH GT 10 U PROBE R	9471.314	
U-238 OUT FLY ASH GT 10 U TOTAL	11912.53	0.25
U-238 OUT FLY ASH 3-10 U	304.7199	0.01
U-238 OUT FLY ASH 1-3 U	7437.597	0.16
U-238 OUT FLY ASH LT 1 U	17746.08	0.38
U-238 OUT FLY ASH TOTAL	37400.93	0.80
U-238 OUT TOTAL	4675892.	
OUT/IN , %	75.69	
RA226 IN COAL	6152877.	99.95
RA226 IN SCRUBBER WATER	3341.52	
RA226 IN TOTAL	6156218.	
RA226 OUT BOTTOM ASH	1156508.	20.19
RA226 OUT MC ASH	3227598.	56.34
RA226 OUT VS SPENT SOLID	1261242.	22.02
RA226 OUT VS SPENT LIQUID	2563.22	0.04
RA226 OUT FLY ASH GT 10 U	10405.17	
RA226 OUT FLY ASH GT 10 U PROBE R	40456.94	
RA226 OUT FLY ASH GT 10 U TOTAL	50862.11	0.89
RA226 OUT FLY ASH 3-10 U	694.4780	0.01
RA226 OUT FLY ASH 1-3 U	9161.332	0.16
RA226 OUT FLY ASH LT 1 U	20044.00	0.35
RA226 OUT FLY ASH TOTAL	80761.92	1.41
RA226 OUT TOTAL	5728673.	
OUT/IN, %	93.06	

TABLE B-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
PO210 IN COAL	6152877.	99.85
PO210 IN SCRUBBER WATER	9369.36	
PO210 IN TOTAL	6162246.	
PO210 OUT BOTTOM ASH	536794.2	16.76
PO210 OUT MC ASH	1308027.	40.84
PO210 OUT VS SPENT SOLID	1219200.	38.07
PO210 OUT VS SPENT LIQUID	5424.4	0.17
PO210 OUT FLY ASH GT 10 U	8697.655	
PO210 OUT FLY ASH GT 10 U PROBE R	55134.34	
PO210 OUT FLY ASH GT 10 U TOTAL	63832.00	1.99
PO210 OUT FLY ASH 3-10 U	793.6891	0.02
PO210 OUT FLY ASH 1-3 U	18929.16	0.59
PO210 OUT FLY ASH LT 1 U	49936.21	1.56
PO210 OUT FLY ASH TOTAL	133491.1	4.17
PO210 OUT TOTAL	3202937.	
OUT/IN, %	51.98	
PB210 IN COAL	6152877.	
PB210 IN SCRUBBER WATER	0	
PB210 IN TOTAL	6152877.	
PB210 OUT BOTTOM ASH	0	
PB210 OUT MC ASH	0	
PB210 OUT VS SPENT SOLID	0	
PB210 OUT VS SPENT LIQUID	0	
PB210 OUT FLY ASH GT 10 U	0	
PB210 OUT FLY ASH GT 10 U PROBE R	0	
PB210 OUT FLY ASH GT 10 U TOTAL	0	
PB210 OUT FLY ASH 3-10 U	0	
PB210 OUT FLY ASH 1-3 U	0	
PB210 OUT FLY ASH LT 1 U	0	
PB210 OUT FLY ASH TOTAL	0	
PB210 CUT TOTAL	0	
OUT/IN, %	0	

TABLE B-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
TH230 IN COAL	6152877.	99.99
TH230 IN SCRUBBER WATER	589.68	
TH230 IN TOTAL	6153466.	
TH230 OUT BOTTOM ASH	1803861.	42.02
TH230 OUT MC ASH	2279137.	53.09
TH230 OUT VS SPENT SOLID	149246.9	3.48
TH230 OUT VS SPENT LIQUID	2765.68	0.06
TH230 OUT FLY ASH GT 10 U	1044.964	
TH230 OUT FLY ASH GT 10 U PROBE R	34498.17	
TH230 OUT FLY ASH GT 10 U TOTAL	35543.13	0.83
TH230 OUT FLY ASH 3-10 U	385.7086	0.01
TH230 OUT FLY ASH 1-3 U	5490.415	0.13
TH230 OUT FLY ASH LT 1 U	16278.51	0.38
TH230 OUT FLY ASH TOTAL	57697.76	1.34
TH230 OUT TOTAL	4292709.	
OUT/IN, %	69.76	
TH232 IN COAL	5438148.	99.98
TH232 IN SCRUBBER WATER	959.868	
TH232 IN TOTAL	5439108.	
TH232 OUT BOTTOM ASH	586982.2	14.71
TH232 OUT MC ASH	2590572.	64.91
TH232 OUT VS SPENT SOLID	788276.1	19.75
TH232 OUT VS SPENT LIQUID	1230.04	0.03
TH232 OUT FLY ASH GT 10 U	595.8517	
TH232 OUT FLY ASH GT 10 U PROBE R	4171.142	
TH232 OUT FLY ASH GT 10 U TOTAL	4766.993	0.12
TH232 OUT FLY ASH 3-10 U	273.3368	0.01
TH232 OUT FLY ASH 1-3 U	3080.378	0.08
TH232 OUT FLY ASH LT 1 U	15621.96	0.39
TH232 OUT FLY ASH TOTAL	23742.67	0.59
TH232 OUT TOTAL	3990803.	
OUT/IN, %	73.37	

TABLE B-5. MECHANICAL COLLECTOR (INLET AND OUTLET) AND VENTURI SCRUBBER (INLET) RADIONUCLIDE DATA

RADIONUCLIDE/STREAM DESCRIPTION		pCi/hr
U-238	MECHANICAL COLLECTOR INLET	4740277.
U-238	MECHANICAL COLLECTOR OUTLET	2046133.
U-238	VENTURI SCRUBBER INLET	1649162.
RA-226	MECHANICAL COLLECTOR INLET	3728457.
RA-226	MECHANICAL COLLECTOR OUTLET	1019166.
RA-226	VENTURI SCRUBBER INLET	1783033.
PO-210	MECHANICAL COLLECTOR INLET	6644366.
PO-210	MECHANICAL COLLECTOR OUTLET	3468642.
PO-210	VENTURI SCRUBBER INLET	2389162.
PB-210	MECHANICAL COLLECTOR INLET	0
PB-210	MECHANICAL COLLECTOR OUTLET	0
PB-210	VENTURI SCRUBBER INLET	0
TH-230	MECHANICAL COLLECTOR INLET	5214233.
TH-230	MECHANICAL COLLECTOR OUTLET	1594722.
TH-230	VENTURI SCRUBBER INLET	1143460.
TH-232	MECHANICAL COLLECTOR INLET	2941582.
TH-232	MECHANICAL COLLECTOR OUTLET	1052876.
TH-232	VENTURI SCRUBBER INLET	1325185.

TABLE B-6. ANALYTICAL DATA AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY

	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
(1) ANALYTICAL DATA--						
HCSS thimble pCi/thimble	0.3 ± 0.1	0.4 ± 0.2	<0.2	NA	0.46 ± 0.08	0.3 ± 0.07
HCSS thimble pCi/thimble	0.2 ± 0.09	1.4 ± 0.3	0.4 ± 0.2	NA	0.27 ± 0.07	0.3 ± 0.08
0.1 HNO_3, pCi/l	<0.4	3.0 ± 1.0	<2.0	NA	<0.4	0.6 ± 0.3
Water (DDI), pCi/l	<0.07	<0.5	<0.8	NA	<0.1	0.2 ± 0.2
SASS filter pCi/filter	0.8 ± 0.1	0.9 ± 0.3	0.7 ± 0.3	NA	0.8 ± 0.1	1.1 ± 0.1
SASS filter pCi/filter	0.9 ± 0.2	1.7 ± 0.3	0.8 ± 0.2	NA	0.5 ± 0.09	0.9 ± 0.1
(2) FILTER AND THIMBLE (<1 μm) SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, μCi/hr--						
MC inlet (1 filter)	ND	0.09	0.02	NA	0.03	0.02
MC outlet (1 filter)	0.01	NA	0.1	NA	0.002	0.004
Scrubber inlet (2 filters)	0.005	0.01	NA	NA	0.02	NA
Scrubber outlet (1 filter)	0.008	ND	0.03	NA	0.003	ND

NA = No analysis.

ND = Not detectable.

APPENDIX C

APPLE III OUTPUT AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, SITE M-33

TABLE C-1. SITE M-33 INPUT DATA (MEASURED AND CALCULATED)

DCR,G/HR	DESIGN COAL FEED RATE	4.7947E8
LF, f	LOAD FACTOR, FRACTION	.82
ACR,G/HR	ACTUAL COAL FEED RATE	3.9317E8
CAC,f	COAL ASH CONTENT, FRACTION	.151
AIN,G/HR	ASH INPUT RATE	59367975
FA,G	FLY ASH INLET N TOTAL	11.87561
FA,G	FLY ASH INLET S TOTAL	69.29409
FA,G	FLY ASH OUTLET TOTAL	6.62176
TVS,DSCF	TOTAL VOLUME SAMPLED INLET N	56.549
TVS,DSCF	TOTAL VOLUME SAMPLED INLET S	329.283
TVS,DSCF	TOTAL VOLUME SAMPLED OUTLET	857.148
TF,DSCFM	TOTAL FLOW INLET N	791154
TF,DSCFM	TOTAL FLOW INLET S	795936
TF,DSCFM	TOTAL FLOW OUTLET	1227487
CONSTANT	INLET N	839435.5
CONSTANT	INLET S	145030.7
CONSTANT	OUTLET	85923.57
FAR,G/HR	TOTAL FLY ASH RATE INLET N	9968809.
FAR,G/HR	TOTAL FLY ASH RATE INLET S	10049774
FAR,G/HR	TOTAL FLY ASH RATE OUTLET	568965.3
BAR,G/HR	BOTTOM ASH RATE	39349393
ESPA,G/HR	ESP HOPPER ASH RATE	19449617
ESPEFF,%	ESP EFFICIENCY	97.15781
FA,G	FLY ASH INLET N GT 10 U PC	8.24029
FA,G	FLY ASH INLET N GT 10 U 1st STAGE	.06076
FA,G	FLY ASH INLET N 3-10 U 2nd STAGE	.58706
FA,G	FLY ASH INLET N 1-3 U 3rd STAGE	1.53272
FA,G	FLY ASH INLET N THIMBLES LT 1 U	1.04643
FA,G	FLY ASH INLET N IMPACTOR RINSE LT 1 U	.40835
FA,G	FLY ASH INLET S GT 10 U	39.6098
FA,G	FLY ASH INLET S GT 10 U PR	.31885
FA,G	FLY ASH INLET S 3-10 U	23.82211
FA,G	FLY ASH INLET S 1-3 U	4.95765
FA,G	FLY ASH INLET S LT 1 U	.58568
FA,G	FLY ASH OUTLET GT 10 U	2.96403
FA,G	FLY ASH OUTLET GT 10 U PR	.26001
FA,G	FLY ASH OUTLET 3-10 U	2.39876
FA,G	FLY ASH OUTLET 1-3 U	.86937
FA,G	FLY ASH OUTLET LT 1 U	.12959

TABLE C-1. (CONT'D)

FAR, G/HR	FLY ASH RATE INLET N GT 10 U PC
FAR, G/HR	FLY ASH RATE INLET N GT 10 U 1st STAGE
FAR, G/HR	FLY ASH RATE INLET N 3-10 U 2nd STAGE
FAR, G/HR	FLY ASH RATE INLET N 1-3 U 3rd STAGE
FAR, G/HR	FLY ASH RATE INLET N LT 1 U THIMBLES
FAR, G/HR	FLY ASH RATE INLET N LT 1 U IMPACTOR RINSE
FAR, G/HR	FLY ASH RATE INLET S GT 10 U
FAR, G/HR	FLY ASH RATE INLET S GT 10 U PR
FAR, G/HR	FLY ASH RATE INLET S 3-10 U
FAR, G/HR	FLY ASH RATE INLET S 1-3 U
FAR, G/HR	FLY ASH RATE INLET S LT 1 U
FAR, G/HR	FLY ASH RATE OUTLET GT 10 U
FAR, G/HR	FLY ASH RATE OUTLET GT 10 U PR
FAR, G/HR	FLY ASH RATE OUTLET 3-10 U
FAR, G/HR	FLY ASH RATE OUTLET 1-3 U
FAR, G/HR	FLY ASH RATE OUTLET LT 1 U
BAR, L/HR	BOTTOM ASH RATE (CONVERTED TO L/HR)
ASR, L/HR	ASH SLUICE RATE, WATER AND ASH
BAWR, L/HR	BOTTOM ASH WATER SLUICE RATE
ESPA, L/HR	ESP ADDITIVE RATE--#5041
ESPA, L/HR	ESP ADDITIVE RATE--#5003

FAR, G/HR		6917192.
FAR, G/HR		51004.10
FAR, G/HR		492799.0
FAR, G/HR		1286620.
FAR, G/HR		878410.5
FAR, G/HR		342783.5
FAR, G/HR		5744639.
FAR, G/HR		46243.05
FAR, G/HR		3454938.
FAR, G/HR		719011.7
FAR, G/HR		84941.61
FAR, G/HR		254680.1
FAR, G/HR		22340.99
FAR, G/HR		206110.0
FAR, G/HR		74699.38
FAR, G/HR		11134.84
BAR, L/HR	*	61355.58
ASR, L/HR	*	55157908
BAWR, L/HR	*	55096552
ESPA, L/HR		327.8
ESPA, L/HR		82

TABLE C-2. ACTIVITY DATA AS REPORTED BY EPA LABORATORY

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/G or pCi/L)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	1.12	NC	NC	NC	1	.719
E	.1029				.0689	.0789
ESPAD5041 pCi/L	1.326	NC	NC	NC	.9688	.2106
E	.4921				.4852	.9036
ESPAD5003 pCi/L	5.778	NC	NC	NC	3.431	.225
E	.2004				.2929	1.232
BOTASH/D pCi/L	4.946	.8	0	19.106	.659	.2355
E	.2313	.27	.3974	.8463	.5358	.8951
BOTASH/U pCi/L	.3795	9.8	NC	NC	5.282	3.766
E	.742	.05			.1861	.2247
WATER/D pCi/L	.2717	.14	NC	NC	.0174	.00435
E	.2632	.2			1.4144	3.4652
WATER/U pCi/L	.03301	.34	NC	NC	.06446	.03008
E	1.5847	.09			.5175	.858
ESP ASH	3.517	4	6.73	5.562	3.132	2.127
E	.1142	.02	.1671	.2778	.0561	.0654
FLY ASH OUT >10u	2.522	3.6	B	6.508	3.254	2.145
E	.1345	.03		2.3121	.0813	.0974
FLY ASH OUT 3-10u	4.578	3.8	5.18	10.699	3.622	2.559
E	.1163	.02	.1817	.4004	.0726	.0841
FLY ASH OUT 1-3 u	6.597	3.6	22.43	8.836	3.659	2.607
E	.1129	.03	.1549	.5653	.0887	.103
FLY ASH OUT <1u	15.6	7.72	100.14	B	10.22	8.81
E	.1598	.08	.1689		.1681	.1836
FLY ASH OUT >10u P	4.47	12.3	1.52	28.54	4.02	1.99
E	.1902	.04	.2647	.9433	.1838	.2585

THE FOLLOWING DATA SETS ARE USED WITHOUT THEIR ERROR VALUES :

FAIN PC GT 10 U	2.602	3.2	B	4.073	3.083	2.114
FAIN 1st GT 10 U	7.08	7.24	183.46	B	4.81	3.25
FAIN 2nd 3-10 U	4.14	4.43	.76	15.91	8.92	5.98
FAIN 3rd 1-3 U	5.35	4.89	10.79	9.35	1.18	.83
FAIN THMB LT 1 U	4.37	2.48	7.39	16.42	1.79	1.26
FAIN IR LT 1 U	4.17	8.33	5.37	7.86	2.6	1.73
FAIS GT 10 U	2.235	2.5	1.81	.556	3.455	2.243
FAIS 3-10 U	4.136	4.4	4.43	8.33	3.581	2.398
FAIS 1-3 U	6.538	6.2	19.59	9.068	3.666	2.594
FAIS LT 1 U	14.18	13.32	161.1	13.09	6.66	6.68
FAIS PR GT 10 U	3.87	6.9	B	27.37	2.21	1.58

NOTE : NC = NOT COUNTED
B = LESS THAN BACKROUND

TABLE C-3. ACTIVITY DATA AS USED IN CALCULATIONS

SAMPLE DESCRIPTION----	RADIONUCLIDES/ACTIVITIES(pCi/G or pCi/L)/2-S ERROR					
	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	1.12	1.12	1.12	1.12	1	.719
E	.1029	.1029	.1029	.1029	.0689	.0789
ESPAD5041 pCi/L	1.326	0	0	0	.9688	.2106
E	.4921	0	0	0	.4852	.9036
ESPAD5003 pCi/L	5.778	0	0	0	3.431	.225
E	.2004	0	0	0	.2929	1.232
BOTASH/D pCi/L	4.946	.8	0	19.106	.659	.2355
E	.2313	.27	.3974	.8463	.5358	.8951
BOTASH/U pCi/L	.3795	9.8	0	0	5.282	3.766
E	.742	.05	0	0	.1861	.2247
WATER/D pCi/L	.2717	.14	0	0	.0174	.00435
E	.2632	.2	0	0	1.4144	3.4652
WATER/U pCi/L	.03301	.34	0	0	.06446	.03008
E	1.5847	.09	0	0	.5175	.858
ESP ASH	3.517	4	6.73	5.562	3.132	2.127
E	.1142	.02	.1671	.2778	.0561	.0654
FLY ASH OUT >10u	2.522	3.6	0	6.508	3.254	2.145
E	.1345	.03	0	2.3121	.0813	.0974
FLY ASH OUT 3-10u	4.578	3.8	5.18	10.699	3.622	2.559
E	.1163	.02	.1817	.4004	.0726	.0841
FLY ASH OUT 1-3 u	6.597	3.6	22.43	8.836	3.659	2.607
E	.1129	.03	.1549	.5653	.0887	.103
FLY ASH OUT <1u	15.6	7.72	100.14	0	10.22	3.81
E	.1598	.08	.1689	0	.1681	.1836
FLY ASH OUT >10u P	4.47	12.3	1.52	28.54	4.02	1.99
E	.1902	.04	.2647	.9433	.1838	.2585

THE FOLLOWING DATA SETS ARE USED WITHOUT THEIR ERROR VALUES :

FAIN PC GT 10 U	2.602	3.2	0	4.073	3.083	2.114
FAIN 1st GT 10 U	7.08	7.24	183.46	0	4.81	3.25
FAIN 2nd 3-10 U	4.14	4.43	.76	15.91	8.92	5.98
FAIN 3rd 1-3 U	5.35	4.89	10.79	9.35	1.18	.83
FAIN THMB LT 1 U	4.37	2.48	7.39	16.42	1.79	1.26
FAIN IR LT 1 U	4.17	8.33	5.37	7.86	2.6	1.73
FAIS GT 10 U	2.235	2.5	1.81	.556	3.455	2.243
FAIS 3-10 U	4.136	4.4	4.43	8.33	3.581	2.398
FAIS 1-3 U	6.538	6.2	19.59	9.068	3.666	2.594
FAIS LT 1 U	14.18	13.32	161.1	13.09	6.66	6.68
FAIS PR GT 10 U	3.87	6.9	0	27.37	2.21	1.58

TABLE C-4. RADIONUCLIDE BALANCE RESULTS

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
U-238 IN COAL	4.4035E8	100.00
U-238 IN BOTTOM ASH WATER	3392.896	0.00
U-238 IN ESP ADDITIVES	908.4588	0.00
U-238 IN TOTAL	4.4035E8	
U-238 OUT BOTTOM ASH	2.9374E8	80.59
U-238 OUT ESP ASH	68404305	18.77
U-238 OUT FLY ASH GT 10 U PR	99864.22	
U-238 OUT FLY ASH GT 10 U	642303.1	
U-238 OUT FLY ASH GT 10 U TOTAL	742167.3	0.20
U-238 OUT FLY ASH 3-10 U	943571.7	0.26
U-238 OUT FLY ASH 1-3 U	492791.8	0.14
U-238 OUT FLY ASH LT 1 U	173703.4	0.05
U-238 OUT TOTAL FLY ASH	2352234.	0.65
U-238 OUT TOTAL	3.6450E8	
OUT/IN,%	82.78	
RA226 IN COAL	4.4035E8	100.00
RA226 IN BOTTOM ASH WATER	5344.721	0.00
RA226 IN ESP ADDITIVES	0	0.00
RA226 IN TOTAL	4.4035E8	
RA226 OUT BOTTOM ASH	5.8467E8	87.95
RA226 OUT ESP ASH	77798470	11.70
RA226 OUT FLY ASH GT 10 U PR	274794.2	
RA226 OUT FLY ASH GT 10 U	916848.2	
RA226 OUT FLY ASH GT 10 U TOTAL	1191642.	0.18
RA226 OUT FLY ASH 3-10 U	783218.1	0.12
RA226 OUT FLY ASH 1-3 U	268917.8	0.04
RA226 OUT FLY ASH LT 1 U	85960.93	0.01
RA226 OUT TOTAL FLY ASH	2329739.	0.35
RA226 OUT TOTAL	6.6480E8	
OUT/IN,%	150.97	

TABLE C-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
PO210 IN COAL	4.4035E8	100.00
PO210 IN BOTTOM ASH WATER	0	0.00
PO210 IN ESP ADDITIVES	0	0.00
PO210 IN TOTAL	4.4035E8	
PO210 OUT BOTTOM ASH	0	0.00
PO210 OUT ESP ASH	1.3090E8	97.11
PO210 OUT FLY ASH GT 10 U PR	33958.30	
PO210 OUT FLY ASH GT 10 U	0	
PO210 OUT FLY ASH GT 10 U TOTAL	33958.30	0.03
PO210 OUT FLY ASH 3-10 U	1067650.	0.79
PO210 OUT FLY ASH 1-3 U	1675507.	1.24
PO210 OUT FLY ASH LT 1 U	1115042.	0.83
PO210 OUT TOTAL FLY ASH	3892158.	2.89
PO210 OUT TOTAL	1.3479E8	
OUT/IN,%	30.61	
PB210 IN COAL	4.4035E8	100.00
PB210 IN BOTTOM ASH WATER	0	0.00
PB210 IN ESP ADDITIVES	0	0.00
PB210 IN TOTAL	4.4035E8	
PB210 OUT BOTTOM ASH	1.0538E9	90.29
PB210 OUT ESP ASH	1.0818E8	9.27
PB210 OUT FLY ASH GT 10 U PR	637611.8	
PB210 OUT FLY ASH GT 10 U	1657458.	
PB210 OUT FLY ASH GT 10 U TOTAL	2295070.	0.20
PB210 OUT FLY ASH 3-10 U	2205171.	0.19
PB210 OUT FLY ASH 1-3 U	660043.7	0.06
PB210 OUT FLY ASH LT 1 U	0	0.00
PB210 OUT TOTAL FLY ASH	5160285.	0.44
PB210 OUT TOTAL	1.1672E9	
OUT/IN,%	265.06	

TABLE C-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
TH230 IN COAL	3.9317E8	100.00
TH230 IN BOTTOM ASH WATER	911.4977	0.00
TH230 IN ESP ADDITIVES	598.9146	0.00
TH230 IN TOTAL	3.9317E8	
TH230 OUT BOTTOM ASH	3.2769E8	83.88
TH230 OUT ESP ASH	60916202	15.59
TH230 OUT FLY ASH GT 10 U PR	89810.77	
TH230 OUT FLY ASH GT 10 U	828728.9	
TH230 OUT FLY ASH GT 10 U TOTAL	918539.7	0.24
TH230 OUT FLY ASH 3-10 U	746530.5	0.19
TH230 OUT FLY ASH 1-3 U	273325.0	0.07
TH230 OUT FLY ASH LT 1 U	113798.0	0.03
TH230 OUT TOTAL FLY ASH	2052193.	0.53
TH230 OUT TOTAL	3.9066E8	
OUT/IN,%	99.36	
TH232 IN COAL	2.8269E8	100.00
TH232 IN BOTTOM ASH WATER	383.3724	0.00
TH232 IN ESP ADDITIVES	87.48468	0.00
TH232 IN TOTAL	2.8269E8	
TH232 OUT BOTTOM ASH	2.2071E8	83.76
TH232 OUT ESP ASH	41369336	15.70
TH232 OUT FLY ASH GT 10 U PR	44458.57	
TH232 OUT FLY ASH GT 10 U	546288.7	
TH232 OUT FLY ASH GT 10 U TOTAL	590747.3	0.22
TH232 OUT FLY ASH 3-10 U	527435.6	0.20
TH232 OUT FLY ASH 1-3 U	194741.3	0.07
TH232 OUT FLY ASH LT 1 U	98097.91	0.04
TH232 OUT TOTAL FLY ASH	1411022.	0.54
TH232 OUT TOTAL	2.6349E8	
OUT/IN,%	93.21	

TABLE C-5. ELECTROSTATIC PRECIPITATOR INLET RADIONUCLIDE DATA AND ESTIMATION OF WATER SLUICE RATE (TH-230 BALANCE)

RADIONUCLIDE/STREAM DESCRIPTION		pCi/hr Unless Noted
U-238	ESP NORTH INLET	32551307
U-238	ESP SOUTH INLET	33213225
U-238	TOTAL ESP INLET	65764532
RA-226	ESP NORTH INLET	36012799
RA-226	ESP SOUTH INLET	35471698
RA-226	TOTAL ESP INLET	71484498
PO-210	ESP NORTH INLET	31946567
PO-210	ESP SOUTH INLET	53472706
PO-210	TOTAL ESP INLET	85419273
PB-210	ESP NORTH INLET	65161829
PB-210	ESP SOUTH INLET	40871213
PB-210	TOTAL ESP INLET	1.0603E8
TH-230	ESP NORTH INLET	29948604
TH-230	ESP SOUTH INLET	35523667
TH-230	TOTAL ESP INLET	65472271
TH-232	ESP NORTH INLET	20503353
TH-232	ESP SOUTH INLET	23675758
TH-232	TOTAL ESP INLET	44179111
TH-230	BOTTOM ASH (BY DIFFERENCE)	3.2769E8
TOTAL SLUICE RATE L/HR		55157908
WATER SLUICE RATE L/HR		55096552

TABLE C-6. ANALYTICAL DATA AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY

	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
(1) ANALYTICAL DATA--						
HCSS thimbles pCi/2 thimbles	0.3±36%	0.6±17%	1.1±46%	4.0±233%	0.3±32%	0.5±25%
SASS filters pCi/2 filters	1.4±18%	2.1±5%	1.1±30%	7.0±77%	1.6±14%	1.9±13%
0.1 HNO_3, pCi/l	0.4±67%	5.8±11%	0.5±96%	36±36%	0.7±70%	-0.05±200%
Water (DDI), pCi/l	0.2±112%	1.5±19%	0.4±85%	8±161%	2±39%	0.6±67%
(2) FILTER AND THIMBLE (<1 μm) SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, μCi/hr--						
North and South inlets (2 thimbles, 3 filters)	7.8	7.0	70	10	2.7	2.0
ESP outlet (1 filter)	0.08	ND	0.8	ND	0.03	ND

ND = Not detectable.

APPENDIX D

APPLE III OUTPUT AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, SITE M-34

TABLE D-1. SITE M-34 INPUT DATA (MEASURED AND CALCULATED)

DCR, G/HR	DESIGN COAL FEED RATE	6.4994E8
LF, F	LOAD FACTOR, FRACTION	.9025
ACR, G/HR	ACTUAL COAL FEED RATE	5.8657E8
CAC, F	COAL ASH CONTENT, FRACTION	.231
AIN, G/HR	ASH INPUT RATE	1.3550E8
BAR, G/HR	BOTTOM ASH RATE	27099442
FAR, G/HR	FLY ASH RATE ESP INLET	1.0840E8
FA, G	FLY ASH SCRUBBER INLET (1/4)	.03422
FA, G	FLY ASH SCRUBBER OUTLET	.17948
TVS, DSCF	TOTAL VOLUME SAMPLED SCRUBBER INLET (1/4)	46.481
TVS, DSCF	TOTAL VOLUME SAMPLED SCRUBBER OUTLET	953.093
TF, DSCFM	TOTAL FLOW SCRUBBER INLET (1/4)	539656
TF, DSCFM	TOTAL FLOW SCRUBBER OUTLET	2458207
CONSTANT	SCRUBBER INLET (1/4)	696615.0
CONSTANT	SCRUBBER OUTLET	154751.3
FAR, G/HR	FLY ASH RATE SCRUBBER INLET (1/4)	23838.16
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET	27774.77
FAR, G/HR	TOTAL FLY ASH RATE SCRUBBER INLET	108586.1
HAR, G/HR	ESP ASH RATE	1.0829E8
ESPEFF, %	ESP EFFICIENCY	99.89983
SAR, G/HR	SCRUBBER ASH RATE (PARTICULATE)	80811.33
SEFF, %	SCRUBBER EFFICIENCY (PARTICULATE)	74.42143
SSR, L/HR	SCRUBBER SLUDGE RATE UD	1976
SSR, L/HR	SCRUBBER SLUDGE RATE D	20964
LFR, G/HR	LIMESTONE FEED RATE	6782300
SWR, L/HR	SCRUBBER WATER RATE	112000
FA, G	FLY ASH SCRUBBER OUTLET GT 10 U	.0165
FA, G	FLY ASH SCRUBBER OUTLET GT 10 U PRECUTTER	.0233
FA, G	FLY ASH SCRUBBER OUTLET 3-10 U	.07236
FA, G	FLY ASH SCRUBBER OUTLET 1-3 U	.0416
FA, G	FLY ASH SCRUBBER OUTLET LT 1 U	.02572
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET GT 10 U	2553.397
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET GT 10 U PRECUTTER	3605.706
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET 3-10 U	11197.81
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET 1-3 U	6437.656
FAR, G/HR	FLY ASH RATE SCRUBBER OUTLET LT 1 U	3980.204

TABLE D-1. (CONT'D)

FA,G	FLY ASH SCRUBBER INLET GT 10 U PC
FA,G	FLY ASH SCRUBBER INLET GT 10 U 1st STAGE
FA,G	FLY ASH SCRUBBER INLET 3-10 U 2nd STAGE
FA,G	FLY ASH SCRUBBER INLET 1-3 U 3rd STAGE
FA,G	FLY ASH SCRUBBER INLET LT 1 U
FAR,G/HR	FLY ASH RATE SCRUBBER INLET GT 10 U PC
FAR,G/HR	FLY ASH RATE SCRUBBER INLET GT 10 U 1st STAGE
FAR,G/HR	FLY ASH RATE SCRUBBER INLET 3-10 U 2nd STAGE
FAR,G/HR	FLY ASH RATE SCRUBBER INLET 1-3 U 3rd STAGE
FAR,G/HR	FLY ASH RATE SCRUBBER INLET LT 1 U

FA,G	.03085
FA,G	.00016
FA,G	.00063
FA,G	.00223
FA,G	.00035
FAR,G/HR	97892.50
FAR,G/HR	507.7083
FAR,G/HR	1999.101
FAR,G/HR	7076.184
FAR,G/HR	1110.612

TABLE D-2. ACTIVITY DATA AS REPORTED BY EPA LABORATORY

SAMPLE DESCRIPTION----	RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR					
	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	1.66	NC	NC	NC	1.59	1.11
E	.1032				.0597	.0692
LIMESTONE	.5859	NC	NC	NC	.5565	.0769
E	.1772				.1244	.3341
SCRUBBER WATER	.1349	.16	NC	NC	.09548	.04774
E	.4171	.17			.4468	.6565
BOTTOM ASH	2.708	3.7	B	4.562	2.542	1.995
E	.1083	.02		.2398	.0655	.0715
ESP ASH	NC	NC	NC	NC	NC	NC
E						
SCRUBBER SLUDGE UD	21.12	5.8	NC	NC	22.91	2.06
E	.1711	.07			.1013	.3294
SCRUBBER SLUDGE D	1.696	3.8	NC	NC	.6352	.0397
E	.3471	.11			.5601	3.4635
FLY ASH GT 10 U	4.31	14.55	B	558.8	6.72	1.55
E	.7614	.22		.9921	.7059	1.4906
FLY ASH GT 10 U PR	.57	18.88	9.34	B	1.24	B
E	2.6106	.13	.8663		1.4146	
FLY ASH 3-10 U	4.13	11.06	B	164.5	4.33	1.84
E	.3648	.09		.6173	.3258	.4863
FLY ASH 1-3 U	7.05	15.38	B	157.3	3.28	3.09
E	.3747	.1		.8293	.6343	.5009
FLY ASH LT 1 U	33	45.1	118.4	B	28.74	37.45
E	.2203	.07	.296		.2158	.192

THE FOLLOWING DATA SETS ARE USED WITHOUT THEIR ERROR VALUES :
(SCRUBBER INLET-- HCSS RUN)

FASI GT 10 U PC	1.2	5.19	B	93.84	.82	1.1
FASI GT 10 U 1st	74.4	2000	5408	B	153	102
FASI 3-10 U 2nd	128	444	794	205	201	12.5
FASI 1-3 U 3rd	54.1	143	359	B	B	3.94
FASI LT 1 U	440	2400	NC	NC	682	551

NOTE : NC = NOT COUNTED
B = LESS THAN BACKROUND

TABLE D-3. ACTIVITY DATA AS USED IN CALCULATIONS

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	1.66	1.66	1.66	1.66	1.59	1.11
E	.1032	.1032	.1032	.1032	.0597	.0692
LIMESTONE	.5859	.5859	.5859	.5859	.5565	.0769
E	.1772	.1772	.1772	.1772	.1244	.3341
SCRUBBER WATER	.1349	.16	0	0	.09548	.04774
E	.4171	.17	0	0	.4468	.6565
BOTTOM ASH	2.708	3.7	0	4.562	2.542	1.995
E	.1083	.02	.2235	.2398	.0655	.0715
ESP ASH (M-33)	3.517	4	6.73	5.562	3.132	2.127
E	.1142	.02	.1671	.2778	.0561	.0654
SCRUBBER SLUDGE UD	21.12	5.8	0	0	22.91	2.06
E	.1711	.07	0	0	.1013	.3294
SCRUBBER SLUDGE D	1.696	3.8	0	0	.6352	.0397
E	.3471	.11	0	0	.5601	3.4635
FLY ASH GT 10 U	4.31	14.55	0	558.8	6.72	1.55
E	.7614	.22	2.4915	.9921	.7059	1.4906
FLY ASH GT 10 U PR	.57	18.88	9.34	0	1.24	0
E	2.6106	.13	.8663	0	1.4146	0
FLY ASH 3-10 U	4.13	11.06	0	164.5	4.33	1.84
E	.3648	.09	.4977	.6173	.3258	.4863
FLY ASH 1-3 U	7.05	15.38	0	157.3	3.28	3.09
E	.3747	.1	.304	.8293	.6343	.5009
FLY ASH LT 1 U	33	45.1	118.4	0	28.74	37.45
E	.2203	.07	.296	0	.2158	.192

THE FOLLOWING DATA SETS ARE USED WITHOUT THEIR ERROR VALUES :
(SCRUBBER INLET-- HCSS RUN)

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
FASI GT 10 U PC	1.2	5.19	0	93.84	.82	1.1
FASI GT 10 U 1st	74.4	2000	5408	0	153	102
FASI 3-10 U 2nd	128	444	794	205	201	12.5
FASI 1-3 U 3rd	54.1	143	359	0	0	3.94
FASI LT 1 U	440	2400	0	0	682	551

TABLE D-4. RADIONUCLIDE BALANCE RESULTS

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
U-238 IN COAL	9.7370E8	99.59
U-238 IN LIMESTONE	3973750.	0.41
U-238 IN SCRUBBER WATER	15108.8	
U-238 IN TOTAL	9.7769E8	
U-238 OUT BOTTOM ASH	73385288	16.14
U-238 OUT ESP ASH	3.8085E8	83.79
U-238 OUT SPENT SCRUBBER SLUDGE (UD)	41733.12	0.01
U-238 OUT SPENT SCRUBBER SLUDGE (D)	35554.94	0.01
U-238 OUT FLY ASH GT 10 U	11005.14	
U-238 OUT FLY ASH GT 10 U PRECUTTER	2055.253	
U-238 OUT FLY ASH TOTAL GT 10 U	13060.39	0.00
U-238 OUT FLY ASH 3-10 U	46246.94	0.01
U-238 OUT FLY ASH 1-3 U	45385.47	0.01
U-238 OUT FLY ASH LT 1 U	131346.7	0.03
U-238 OUT FLY ASH TOTAL	236039.6	0.05
U-238 OUT TOTAL	4.5455E8	
OUT/IN, %	46.49	
RA226 IN COAL	9.7370E8	99.59
RA226 IN LIMESTONE	3973750.	0.41
RA226 IN SCRUBBER WATER	17920	
RA226 IN TOTAL	9.7769E8	
RA226 OUT BOTTOM ASH	1.0027E8	18.78
RA226 OUT ESP ASH	4.3316E8	81.11
RA226 OUT SPENT SCRUBBER SLUDGE (UD)	11460.8	0.00
RA226 OUT SPENT SCRUBBER SLUDGE (D)	79663.2	0.01
RA226 OUT FLY ASH GT 10 U	37151.93	
RA226 OUT FLY ASH GT 10 U PRECUTTER	68075.73	
RA226 OUT FLY ASH TOTAL GT 10 U	105227.7	0.02
RA226 OUT FLY ASH 3-10 U	123847.7	0.02
RA226 OUT FLY ASH 1-3 U	99011.15	0.02
RA226 OUT FLY ASH LT 1 U	179507.2	0.03
RA226 OUT FLY ASH TOTAL	507593.8	0.10
RA226 OUT TOTAL	5.3402E8	
OUT/IN, %	54.62	

TABLE D-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
PO210 IN COAL	9.7370E8	99.59
PO210 IN LIMESTONE	3973750.	0.41
PO210 IN SCRUBBER WATER	0	
PO210 IN TOTAL	9.7768E8	
PO210 OUT BOTTOM ASH	0	0.00
PO210 OUT ESP ASH	7.2879E8	99.93
PO210 OUT SPENT SCRUBBER SLUDGE (UD)	0	0.00
PO210 OUT SPENT SCRUBBER SLUDGE (D)	0	0.00
PO210 OUT FLY ASH GT 10 U	0	
PO210 OUT FLY ASH GT 10 U PRECUTTER	33677.30	
PO210 OUT FLY ASH TOTAL GT 10 U	33677.30	0.00
PO210 OUT FLY ASH 3-10 U	0	0.00
PO210 OUT FLY ASH 1-3 U	0	0.00
PO210 OUT FLY ASH LT 1 U	471256.2	0.06
PO210 OUT FLY ASH TOTAL	504933.5	0.07
PO210 OUT TOTAL	7.2929E8	
OUT/IN, %	74.59	
PB210 IN COAL	9.7370E8	99.59
PB210 IN LIMESTONE	3973750.	0.41
PB210 IN SCRUBBER WATER	0	
PB210 IN TOTAL	9.7768E8	
PB210 OUT BOTTOM ASH	1.2363E8	16.93
PB210 OUT ESP ASH	6.0230E8	82.48
PB210 OUT SPENT SCRUBBER SLUDGE (UD)	0	0.00
PB210 OUT SPENT SCRUBBER SLUDGE (D)	0	0.00
PB210 OUT FLY ASH GT 10 U	1426838.	
PB210 OUT FLY ASH GT 10 U PRECUTTER	0	
PB210 OUT FLY ASH TOTAL GT 10 U	1426838.	0.20
PB210 OUT FLY ASH 3-10 U	1842039.	0.25
PB210 OUT FLY ASH 1-3 U	1012643.	0.14
PB210 OUT FLY ASH LT 1 U	0	0.00
PB210 OUT FLY ASH TOTAL	4281521.	0.59
PB210 OUT TOTAL	7.3021E8	
OUT/IN, %	74.69	

TABLE D-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
TH230 IN COAL	9.3264E8	99.60
TH230 IN LIMESTONE	3774350.	0.40
TH230 IN SCRUBBER WATER	10693.76	
TH230 IN TOTAL	9.3643E8	
TH230 OUT BOTTOM ASH	68886780	16.87
TH230 OUT ESP ASH	3.3916E8	83.06
TH230 OUT SPENT SCRUBBER SLUDGE (UD)	45270.16	0.01
TH230 OUT SPENT SCRUBBER SLUDGE (D)	13316.33	0.00
TH230 OUT FLY ASH GT 10 U	17158.83	
TH230 OUT FLY ASH GT 10 U PRECUTTER	4471.076	
TH230 OUT FLY ASH TOTAL GT 10 U	21629.90	0.01
TH230 OUT FLY ASH 3-10 U	48486.50	0.01
TH230 OUT FLY ASH 1-3 U	21115.51	0.01
TH230 OUT FLY ASH LT 1 U	114391.1	0.03
TH230 OUT FLY ASH TOTAL	205623.0	0.05
TH230 OUT TOTAL	4.0831E8	
OUT/IN, %	43.60	
TH232 IN COAL	6.5109E8	99.92
TH232 IN LIMESTONE	521558.9	0.08
TH232 IN SCRUBBER WATER	5346.88	
TH232 IN TOTAL	6.5162E8	
TH232 OUT BOTTOM ASH	54063386	19.00
TH232 OUT ESP ASH	2.3033E8	80.93
TH232 OUT SPENT SCRUBBER SLUDGE (UD)	4070.56	0.00
TH232 OUT SPENT SCRUBBER SLUDGE (D)	832.2708	0.00
TH232 OUT FLY ASH GT 10 U	3957.766	
TH232 OUT FLY ASH GT 10 U PRECUTTER	0	
TH232 OUT FLY ASH TOTAL GT 10 U	3957.766	0.00
TH232 OUT FLY ASH 3-10 U	20603.96	0.01
TH232 OUT FLY ASH 1-3 U	19892.36	0.01
TH232 OUT FLY ASH LT 1 U	149058.7	0.05
TH232 OUT FLY ASH TOTAL	193512.7	0.07
TH232 OUT TOTAL	2.8459E8	
OUT/IN, %	43.67	

TABLE D-5. WET LIMESTONE SCRUBBER INLET RADIONUCLIDE DATA

RADIONUCLIDE/STREAM DESCRIPTION	pCi/hr
U-238 SCRUBBER INLET (1/4 DUCTS--MEASURED)	1282620.
U-238 SCRUBBER INLET (TOTAL--ESTIMATED)	5842511.
RA-226 SCRUBBER INLET (1/4 DUCTS--MEASURED)	6088442.
RA-226 SCRUBBER INLET (TOTAL--ESTIMATED)	27733688
PO-210 SCRUBBER INLET (1/4 DUCTS--MEASURED)	6873323.
PO-210 SCRUBBER INLET (TOTAL--ESTIMATED)	31308926
PB-210 SCRUBBER INLET (1/4 DUCTS--MEASURED)	9596048.
PB-210 SCRUBBER INLET (TOTAL--ESTIMATED)	43711312
TH-230 SCRUBBER INLET (1/4 DUCTS--MEASURED)	1317208.
TH-230 SCRUBBER INLET (TOTAL--ESTIMATED)	6000062.
TH-232 SCRUBBER INLET (1/4 DUCTS--MEASURED)	824284.0
TH-232 SCRUBBER INLET (TOTAL--ESTIMATED)	3754727.

TABLE D-6. ANALYTICAL DATA AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY

	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
(1) ANALYTICAL DATA--						
HCSS thimbles pCi/2 thimbles	0.3 ± 36%	0.6 ± 17%	1.1 ± 46%	4.0 ± 233%	0.3 ± 32%	0.5 ± 25%
SASS filters pCi/2 filters	1.4 ± 18%	2.1 ± 5%	1.1 ± 30%	7.0 ± 77%	1.6 ± 14%	1.9 ± 13%
0.1 HNO_3, pCi/l	0.4 ± 67%	5.8 ± 11%	0.5 ± 96%	36 ± 36%	0.7 ± 70%	-0.05 ± 200%
Water (DDI), pCi/l	0.2 ± 112%	1.5 ± 19%	0.4 ± 85%	8 ± 161%	2 ± 39%	0.6 ± 67%
(2) FILTER AND THIMBLE (<1 μm) SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, μCi/hr--						
Scrubber inlet (1 thimble)	ND	ND	NA	NA	ND	ND
Scrubber outlet (1 filter)	0.03	0.02	0.48	ND	ND	ND

NA = No analysis.

ND = Not detectable.

APPENDIX E

APPLE III OUTPUT AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, SITE M-99

TABLE E-1. SITE M-99 INPUT DATA (MEASURED AND CALCULATED)

DCR, G/HR	DESIGN COAL FEED RATE	53167229
LF, f	LOAD FACTOR, FRACTION	.83
ACR, G/HR	ACTUAL COAL FEED RATE	44128800
CAC, f	COAL ASH CONTENT, FRACTION	.0903
AIN, G/HR	ASH INPUT RATE	3984831.
FA, G	ESP EAST INLET TOTAL	4.46026
FA, G	ESP WEST INLET TOTAL	16.55137
FA, G	ESP OUTLET TOTAL	2.64908
TVS, DSCF	TOTAL VOLUME SAMPLED ESP EAST INLET	110.675
TVS, DSCF	TOTAL VOLUME SAMPLED ESP WEST INLET	399.439
TVS, DSCF	TOTAL VOLUME SAMPLED ESP OUTLET	1752.978
TF, DSCFM	TOTAL FLOW ESP EAST INLET	91391
TF, DSCFM	TOTAL FLOW ESP WEST INLET	94064
TF, DSCFM	TOTAL FLOW ESP OUTLET	219303
CONSTANT	ESP EAST INLET	49545.61
CONSTANT	ESP WEST INLET	14129.42
CONSTANT	ESP OUTLET	7506.187
FAR, G/HR	FLY ASH RATE ESP EAST INLET	220986.3
FAR, G/HR	FLY ASH RATE ESP WEST INLET	233861.2
FAR, G/HR	FLY ASH RATE ESP OUTLET	19884.49
HAR, G/HR	ESP HOPPER ASH RATE	434963.0
ESPEFF, %	ESP EFFICIENCY	95.62832
BAR, G/HR *	BOTTOM ASH RATE	2390898.
CYIN, G/HR*	CYCLONE INLET ASH RATE	1593932.
CYAR, G/HR*	CYCLONE HOPPER ASH RATE	1139085.
CYCEFF, %*	CYCLONE EFFICIENCY	71.46391
FA, G	FLY ASH ESP OUTLET GT 10 U	.6935
FA, G	FLY ASH ESP OUTLET GT 10 U PROBE RINSE	.7538
FA, G	FLY ASH ESP OUTLET 3-10 U	.44105
FA, G	FLY ASH ESP OUTLET 1-3 U	.31199
FA, G	FLY ASH ESP OUTLET LT 1 U	.44874
FAR, G/HR	FLY ASH RATE ESP OUTLET GT 10 U	5205.540
FAR, G/HR	FLY ASH RATE ESP OUTLET GT 10 U PROBE RINSE	5658.163
FAR, G/HR	FLY ASH RATE ESP OUTLET 3-10 U	3310.604
FAR, G/HR	FLY ASH RATE ESP OUTLET 1-3 U	2341.855
FAR, G/HR	FLY ASH RATE ESP OUTLET LT 1 U	3368.326
FA, G	FLY ASH ESP WEST INLET GT 10 U	5.2637
FA, G	FLY ASH ESP WEST INLET GT 10 U PR	.43597
FA, G	FLY ASH ESP WEST INLET 3-10 U	2.45996
FA, G	FLY ASH ESP WEST INLET 1-3 U	1.5057
FA, G	FLY ASH ESP WEST INLET LT 1 U	6.88604
FA, G	FLY ASH ESP EAST INLET GT 10 U 1st STAGE	1.94531
FA, G	FLY ASH ESP EAST INLET GT 10 U IR	.52674
FA, G	FLY ASH ESP EAST INLET 3-10 U 2nd STAGE	.14918
FA, G	FLY ASH ESP EAST INLET 1-3 U 3rd STAGE	.23108
FA, G	FLY ASH ESP EAST INLET LT 1 U	1.60795
FAR, G/HR	FLY ASH RATE ESP WEST INLET GT 10 U	74373.01
FAR, G/HR	FLY ASH RATE ESP WEST INLET GT 10 U PR	6160.002
FAR, G/HR	FLY ASH RATE ESP WEST INLET 3-10 U	34757.80
FAR, G/HR	FLY ASH RATE ESP WEST INLET 1-3 U	21274.66
FAR, G/HR	FLY ASH RATE ESP WEST INLET LT 1 U	97295.73
FAR, G/HR	FLY ASH RATE ESP EAST INLET GT 10 U 1st STAGE	96381.56
FAR, G/HR	FLY ASH RATE ESP EAST INLET GT 10 U IR	26097.65
FAR, G/HR	FLY ASH RATE ESP EAST INLET 3-10 U 2nd STAGE	7391.214
FAR, G/HR	FLY ASH RATE ESP EAST INLET 1-3 U 3rd STAGE	11449.00
FAR, G/HR	FLY ASH RATE ESP EAST INLET LT 1 U	79666.86

TABLE E-2. ACTIVITY DATA AS REPORTED BY EPA LABORATORY

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	.342	.249	.779	NC	1.48	.399
E	.0018	.000887	.00421		.0064	0
BOTTOM ASH	1.31	NC	.88	NC	1.99	.662
E	.00278		0		.00457	.00275
MC ASH	2.61	3.19	1.2	NC	2.68	1.72
E	.00233	.00179	.0016		.00635	.00479
ESP ASH	1.75	1.52	13.7	NC	1.76	.954
E	.0032	.0077	.0188		.00373	.00276
FLY ASH GT 10 U	.359	.8	26.4	NC	.241	.262
E	.00131	.00424	.0232		.00114	.00118
FLY ASH GT 10 U P	.12	.917	25.6	NC	.108	.115
E	0	.003	.0167		0	0
FLY ASH 3-10 U	.213	.582	28.1	NC	.405	.173
E	.00111	.00371	.0248		.00152	0
FLY ASH 1-3 U	.282	1.26	25.9	NC	.465	.178
E	.00147	.00643	.0298		.00146	.000929
FLY ASH LT 1 U	2.52	2.99	24.5	NC	2.5	2.38
E	.00394	.00305	.0208		.00238	.0023

THE FOLLOWING DATA SETS USED WITHOUT THEIR ERROR VALUES :
(ELECTROSTATIC PRECIPITATOR EAST AND WEST INLET DATA)

ESP W I GT 10 U	1.83	3.61	3.16	NC	1.4	2.21
ESP W I GT 10 U PR	1.9	4.44	14.9	NC	1.14	1.09
ESP W I 3-10 U	2.03	2.16	10.8	NC	2.27	1.18
ESP W I 1-3 U	1.19	1.39	26	NC	.932	.627
ESP W I LT 1 U	.07	.084	.114	NC	.07	.038
ESP E I GT 10 U	2.11	2.61	5.74	NC	2.03	1.41
ESP E I GT 10 U IR	1.02	1.75	8.94	NC	1.73	1.19
ESP E I 3-10 U	1.81	2.63	20.4	NC	6.87	1.08
ESP E I 1-3 U	1.4	3.59	16	NC	1.87	1.01
ESP E I LT 1 U	.36	.38	27.1	NC	.78	.54

NOTE : NC = NOT COUNTED AND
ALL VALUES FOR PO-210 ARE
"LESS THAN" VALUES

TABLE E-3. ACTIVITY DATA AS USED IN CALCULATIONS

SAMPLE DESCRIPTION----RADIONUCLIDES/ACTIVITIES(pCi/L or pCi/G)/2-S ERROR

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
COAL	.342	.249	.779	0	1.48	.399
E	.0018	.000887	.00421	0	.0064	0
BOTTOM ASH	1.31	0	.88	0	1.99	.662
E	.00278	0	0	0	.00457	.00275
MC ASH	2.61	3.19	1.2	0	2.68	1.72
E	.00233	.00179	.0016	0	.00635	.00479
ESP ASH	1.75	1.52	13.7	0	1.76	.954
E	.0032	.0077	.0188	0	.00373	.00276
FLY ASH GT 10 U	.359	.8	26.4	0	.241	.262
E	.00131	.00424	.0232	0	.00114	.00118
FLY ASH GT 10 U P	.12	.917	25.6	0	.108	.115
E	0	.003	.0167	0	0	0
FLY ASH 3-10 U	.213	.582	28.1	0	.405	.173
E	.00111	.00371	.0248	0	.00152	0
FLY ASH 1-3 U	.282	1.26	25.9	0	.465	.178
E	.00147	.00643	.0298	0	.00146	.000929
FLY ASH LT 1 U	2.52	2.99	24.5	0	2.5	2.38
E	.00394	.00305	.0208	0	.00238	.0023

THE FOLLOWING DATA SETS USED WITHOUT THEIR ERROR VALUES :
(ELECTROSTATIC PRECIPITATOR EAST AND WEST INLET DATA)

	U-238	RA-226	PO-210	PB-210	TH-230	TH-232
ESP W I GT 10 U	1.83	3.61	3.16	0	1.4	2.21
ESP W I GT 10 U PR	1.9	4.44	14.9	0	1.14	1.09
ESP W I 3-10 U	2.03	2.16	10.8	0	2.27	1.18
ESP W I 1-3 U	1.19	1.39	26	0	.932	.627
ESP W I LT 1 U	.07	.084	.114	0	.07	.038
ESP E I GT 10 U	2.11	2.61	5.74	0	2.03	1.41
ESP E I GT 10 U IR	1.02	1.75	8.94	0	1.73	1.19
ESP E I 3-10 U	1.81	2.63	20.4	0	6.87	1.08
ESP E I 1-3 U	1.4	3.59	16	0	1.87	1.01
ESP E I LT 1 U	.36	.38	27.1	0	.78	.54

TABLE E-4. RADIONUCLIDE BALANCE RESULTS

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
U-238 IN COAL	15092050	
U-238 OUT BOTTOM ASH	3132077.	45.53
U-238 OUT CYCLONE ASH	2973011.	43.22
U-238 OUT ESP ASH	761185.2	11.07
U-238 OUT FLY ASH GT 10 U	1868.789	
U-238 OUT FLY ASH GT 10 U PROBE R	678.9796	
U-238 OUT FLY ASH GT 10 U TOTAL	2547.769	0.04
U-238 OUT FLY ASH 3-10 U	705.1586	0.01
U-238 OUT FLY ASH 1-3 U	660.4032	0.01
U-238 OUT FLY ASH LT 1 U	8488.182	0.12
U-238 OUT FLY ASH TOTAL	12401.51	0.18
U-238 OUT TOTAL	6878675.	
OUT/IN, %	45.58	
RA226 IN COAL	10988071	
RA226 OUT BOTTOM ASH	0	0.00
RA226 OUT CYCLONE ASH	3633680.	84.13
RA226 OUT ESP ASH	661143.8	15.31
RA226 OUT FLY ASH GT 10 U	4164.432	
RA226 OUT FLY ASH GT 10 U PROBE R	5188.536	
RA226 OUT FLY ASH GT 10 U TOTAL	9352.968	0.22
RA226 OUT FLY ASH 3-10 U	1926.771	0.04
RA226 OUT FLY ASH 1-3 U	2950.738	0.07
RA226 OUT FLY ASH LT 1 U	10071.30	0.23
RA226 OUT FLY ASH TOTAL	24301.77	0.56
RA226 OUT TOTAL	4319126.	
OUT/IN, %	39.31	

TABLE E-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
PO210 IN COAL	34376335	
PO210 OUT BOTTOM ASH	2103991.	21.15
PO210 OUT CYCLONE ASH	1366902.	13.74
PO210 OUT ESP ASH	5958993.	59.90
PO210 OUT FLY ASH GT 10 U	137426.3	
PO210 OUT FLY ASH GT 10 U PROBE R	144849.0	
PO210 OUT FLY ASH GT 10 U TOTAL	282275.3	2.84
PO210 OUT FLY ASH 3-10 U	93027.96	0.94
PO210 OUT FLY ASH 1-3 U	60654.05	0.61
PO210 OUT FLY ASH LT 1 U	82523.99	0.83
PO210 OUT FLY ASH TOTAL	518481.3	5.21
PO210 OUT TOTAL	9948367.	
OUT/IN, %	28.94	
PB210 IN COAL	0	
PB210 OUT BOTTOM ASH	0	
PB210 OUT CYCLONE ASH	0	
PB210 OUT ESP ASH	0	
PB210 OUT FLY ASH GT 10 U	0	
PB210 OUT FLY ASH GT 10 U PROBE R	0	
PB210 OUT FLY ASH GT 10 U TOTAL	0	
PB210 OUT FLY ASH 3-10 U	0	
PB210 OUT FLY ASH 1-3 U	0	
PB210 OUT FLY ASH LT 1 U	0	
PB210 OUT FLY ASH TOTAL	0	
PB210 OUT TOTAL	0	
OUT/IN, %	0	

TABLE E-4. (CONT'D)

INFLUENT OR EFFLUENT STREAM DESCRIPTION	pCi/hr	Percent of total in/out
TH230 IN COAL	65310624	
TH230 OUT BOTTOM ASH	4757888.	55.40
TH230 OUT CYCLONE ASH	3052747.	35.54
TH230 OUT ESP ASH	765534.9	8.91
TH230 OUT FLY ASH GT 10 U	1254.535	
TH230 OUT FLY ASH GT 10 U PROBE R	611.0817	
TH230 OUT FLY ASH GT 10 U TOTAL	1865.617	0.02
TH230 OUT FLY ASH 3-10 U	1340.794	0.02
TH230 OUT FLY ASH 1-3 U	1088.963	0.01
TH230 OUT FLY ASH LT 1 U	8420.815	0.10
TH230 OUT FLY ASH TOTAL	12716.19	0.15
TH230 OUT TOTAL	8588886.	
OUT/IN, %	13.15	
TH232 IN COAL	17607391	
TH232 OUT BOTTOM ASH	1582775.	39.89
TH232 OUT CYCLONE ASH	1959226.	49.38
TH232 OUT ESP ASH	414954.7	10.46
TH232 OUT FLY ASH GT 10 U	1363.852	
TH232 OUT FLY ASH GT 10 U PROBE R	650.6888	
TH232 OUT FLY ASH GT 10 U TOTAL	2014.540	0.05
TH232 OUT FLY ASH 3-10 U	572.7344	0.01
TH232 OUT FLY ASH 1-3 U	416.8502	0.01
TH232 OUT FLY ASH LT 1 U	8016.616	0.20
TH232 OUT FLY ASH TOTAL	11020.74	0.28
TH232 OUT TOTAL	3967976.	
OUT/IN, %	22.54	

TABLE E-5. ELECTROSTATIC PRECIPITATOR INLET RADIONUCLIDE DATA

RADIONUCLIDE/STREAM DESCRIPTION		pCi/hr
U-238	ESP WEST INLET	250492.5
U-238	ESP EAST INLET	288071.5
U-238	ESP INLET TOTAL	538564.0
RA-226	ESP WEST INLET	408658.4
RA-226	ESP EAST INLET	388041.0
RA-226	ESP INLET TOTAL	796699.4
PO-210	ESP WEST INLET	1266420.
PO-210	ESP EAST INLET	3279480.
PO-210	ESP INLET TOTAL	4545900.
TH-230	ESP WEST INLET	216683.5
TH-230	ESP EAST INLET	375130.9
TH-230	ESP INLET TOTAL	591814.4
TH-232	ESP WEST INLET	229129.4
TH-232	ESP EAST INLET	229520.3
TH-232	ESP INLET TOTAL	458649.7

TABLE E-6. ANALYTICAL DATA AND SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY

	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
(1) ANALYTICAL DATA--						
HCSS thimble pCi/thimble	0.3 ± 0.1	0.4 ± 0.2	<0.2	NA	0.46 ± 0.08	0.3 ± 0.07
HCSS thimble pCi/thimble	0.2 ± 0.09	1.4 ± 0.3	0.4 ± 0.2	NA	0.27 ± 0.07	0.3 ± 0.08
0.1 HNO_3, pCi/l	<0.4	3.0 ± 1.0	<2.0	NA	<0.4	0.6 ± 0.3
Water (DDI), pCi/l	<0.07	<0.5	<0.8	NA	<0.1	0.2 ± 0.2
SASS filter pCi/filter	0.8 ± 0.1	0.9 ± 0.3	0.7 ± 0.3	NA	0.8 ± 0.1	1.1 ± 0.1
SASS filter pCi/filter	0.9 ± 0.2	1.7 ± 0.3	0.8 ± 0.2	NA	0.5 ± 0.09	0.9 ± 0.1
(2) FILTER AND THIMBLE (<1 μm) SAMPLE RESULTS CORRECTED FOR BLANK RADIOACTIVITY, μCi/hr--						
ESP East inlet (3 thimbles)	ND	ND	<2.1	NA	0.01	ND
ESP West inlet (4 filters)	ND	ND	ND	NA	ND	ND
ESP outlet (1 filter)	0.002	ND	<0.08	NA	0.003	0.001

NA = No analysis.

ND = Not detectable.

APPENDIX F

DATA SUMMARY FOR FIVE PLANTS WHERE GRAB SAMPLING (ONLY) WAS CONDUCTED

As discussed in Section 3 of this report, grab sampling (only) was performed at five additional facilities as part of an abbreviated sampling program. The intent during this phase of the project was to concentrate on facilities employing fabric filters for particulate control since it would have been difficult (because of high collection efficiency) to obtain enough material for analysis at the collector outlets at these plants. Grab sample activity analyses for these five sites are given in Table F-1. The reported activities for fabric filter hopper ash are generally higher than activities measured for other collection device samples reported in Sections 4 through 8. Despite the lack of additional confirming data, it is likely that these fabric filters remove much more particulate matter from the gas stream than any of the control devices sampled at the other sites.

TABLE F-1. REPORTED ACTIVITIES FOR FIVE SAMPLING SITES

Site/Stream	Reported activity, pCi/g[a]					
	U-238	Ra-226	Po-210[b]	Pb-210	Th-230	Th-232
M-4						
Fabric Filter Hopper Ash	5.5	4.5	19.0	NC	5.6	2.5
M-16						
Coal[c]						
As Received	0.65	0.85	B	NC	0.32	0.15
Moisture Adjusted Value	0.46	0.61	-	-	0.23	0.11
Fabric Filter Hopper Ash	2.5	4.1	3.3	NC	4.0	2.5
M-18						
Coal[d]						
As Received	0.52	1.8	0.68	NC	0.60	0.40
Moisture Adjusted Value	0.51	1.7	0.67	-	0.59	0.39
Fabric Filter Hopper Ash	6.2	6.8	8.7	NC	6.7	4.6
M-19						
Coal[e]						
As Received	B	0.98	0.70	NC	0.75	0.40
Moisture Adjusted Value	-	0.92	0.66	-	0.70	0.38
Fabric Filter Hopper Ash	2.4	1.2	2.8	NC	3.2	2.6

(continued)

TABLE F-1 (continued)

Site/Stream	Reported activity, pCi/g[a]					
	U-238	Ra-226	Po-210[b]	Pb-210	Th-230	Th-232
M-98						
Coal[f]						
As Received	0.27	NC	0.33	NC	0.34	0.18
Moisture Adjusted Value	0.19	-	0.23	-	0.24	0.12
Bottom Ash	2.5	2.9	1.6	NC	1.5	2.8
Lime	1.3	1.1	0.20	NC	0.13	1.3
Scrubber Sludge - Liquid Portion	17.0	0.31	0.99	NC	0.21	0.54
Scrubber Sludge - Solid Portion	5.3	2.6	2.8	NC	4.8	6.4

[a] B = less than background, NC = not counted.

[b] No decay correction made.

[c] Moisture Content - 28.6%, Ash Content - 5.81%, Sulfur Content - 0.37%, Heating Value - 8,575 Btu/lb.

[d] Moisture Content - 1.53%, Ash Content - 8.20%, Sulfur Content - 0.77%, Heating Value - 13,815 Btu/lb.

[e] Moisture Content - 6.24%, Ash Content - 13.6%, Sulfur Content, 1.78%, Heating Value - 12,370 Btu/lb.

[f] Moisture Content - 30.8%, Ash Content - 9.0%, Sulfur Content - 0.79%, Heating Value - 7,143 Btu/lb.

APPENDIX G

SUMMARY OF RADIOASSAY RESULTS FOR TWO FLUIDIZED BED BOILERS - THE GEORGETOWN UNIVERSITY FBB AND THE EXXON MINIPLANT

GEORGETOWN UNIVERSITY FLUIDIZED-BED BOILER RADIOASSAY RESULTS[1]

PLANT DESCRIPTION

The Georgetown University fluidized-bed boiler (FBB) is a two-bed, single-cell, top-suspended, balanced-draft, natural circulation boiler unit capable of generating saturated steam at 275 psig for delivery directly into the University steam header for heating and cooling of 204,000 m^2 of bulding space. Saturated steam at 625 psig can also be produced for delivery into the University header through a pressure regulating valve, with provisions for future co-generation of electrical energy.

The design and operation of the Georgetown University FBB is based on classical fluidized-bed principles; i.e., use of low superficial velocity in the range of 1.2 to 2.4 m/sec (4 to 8 ft/sec), and primary recirculation of entrained solids to the combustion chamber. Design and operating conditions for the FBB are summarized in Table G-1 while a schematic diagram of the plant configuration is provided in Figure G-1.

SAMPLING PERFORMED

Five stream samples were collected at the Georgetown FBB for radioisotopic analysis. Stream numbers refer to the sampling points indicated in Figure G-1. These included combustor flue gas particles (upstream of the baghouse), spent combustion bed solids, fly ash removed from the baghouse hoppers, coal feed, and limestone feed.

The Source Assessment Sampling System (SASS train) was used to collect size-fractionated particles in the Georgetown FBB combustor flue gas for radioanalysis. SASS train sampling was conducted using a sampling port located on a duct between the outlet of the multiclone and inlet to the baghouse. This location was selected to provide sufficient particulate material for radioanalysis. Sampling at the baghouse outlet would not have yielded enough sample because of the high particulate removal efficiency of the baghouse.

A total of 9.26 dscm of combustor flue gas was sampled over a 90 minute period on August 25, 1980. On August 26, a SASS train sampling run was conducted at the baghouse outlet to provide information to estimate baghouse efficiency. A total of 29.22 dscm were sampled at this location.

Table G-2 shows net weight of flue gas particles collected for each component of the SASS train for both inlet and outlet sampling. Using these data and normalizing the volume of flue gas sampled, an approximate baghouse removal efficiency may be calculated for each particulate size fraction. It should be emphasized that this calculation efficiency is only an estimate based on SASS-train data obtained from two separate sampling runs. These values are used to project the radionuclide emissions at the stack based on the measured activities at the baghouse inlet. The estimating procedure should be considered as a rough approximation only.

TABLE G-1. GEORGETOWN UNIVERSITY FLUIDIZED-BED BOILER DESIGN/OPERATING CONDITIONS

Steam flow	100,000 lbs/hr
Outlet temperature/pressure	Saturated 414°F/275 or 493°F/625 psig
Bed dimensions	19'-4" x 11'-0 (2 segments)
Design coal	Bituminous
Heating value	12,750 Btu/lb
Ash content	7.9 percent
Moisture content	5.0 percent
Sulfur content	3.29 percent
Design parameters	
Bed depth - expanded at full load	4-1/2 ft
Bed operating temperature	1594°F
Fluidizing velocity at full load	8 ft/sec
Freeboard height	8 ft
Bed tubes	Sloped
Segment separation	Partition wall
Ca/S ratio (for SO_2 compliance)	3/1
Coal feed system	Stoker (2) - side wall mount
Coal size	1-1/4" x 1/4"
Coal flow rate at full load	9,565 lbs/hr
Limestone size	1/8" x 16 mesh (0.0469")
Reinjection flow rate at full load	7,500 lbs/hr
Efficiency (thermal)	83.51 percent
Turndown capacity	4 to 1

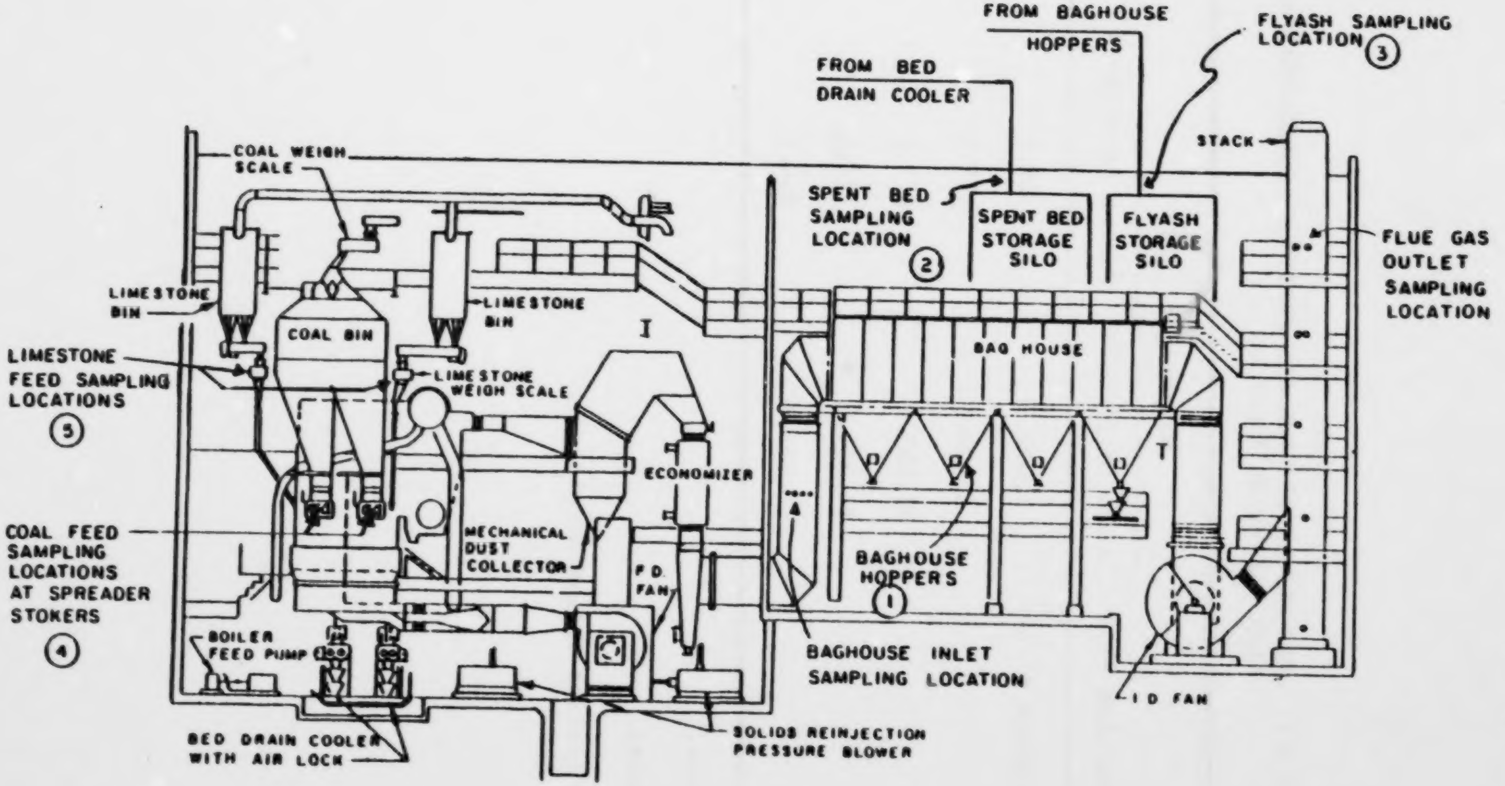
FROM BAGHOUSE
HOPPERS
FLYASH SAMPLING LOCATION ③
FROM BED
DRAIN COOLER
STACK
COAL WEIGH SCALE
SPENT BED SAMPLING LOCATION ②
SPENT BED STORAGE SILO
FLYASH STORAGE SILO
FLUE GAS OUTLET SAMPLING LOCATION
LIMESTONE BIN
COAL BIN
LIMESTONE BIN
LIMESTONE FEED SAMPLING LOCATIONS ⑤
LIMESTONE WEIGH SCALE
BAG HOUSE
ECONOMIZER
COAL FEED SAMPLING LOCATIONS AT SPREADER STOKERS ④
MECHANICAL DUST COLLECTOR
P.D. FAN
BAGHOUSE HOPPERS
①
BOILER FEED PUMP
BAGHOUSE INLET SAMPLING LOCATION
I D FAN
BED DRAIN COOLER WITH AIR LOCK
SOLIDS REINJECTION PRESSURE BLOWER

Figure G-1. FBB system schematic illustrating particulate control equipment and all sampling points.

TABLE G-2. NET WEIGHT OF FLUE GAS PARTICLES COLLECTED FOR EACH SASS-SIZE FRACTION

SASS-size fraction	Net weight (mg)		Removal efficiency[c] (%)
	Inlet (8/25/80)[a]	Outlet (8/26/80)[b]	
3 filters (particles <1 μm)	2,032.5	49.5	99.23
1 μm cyclone	8,808.6	127.5	99.54
3 μm cyclone	45,105.9	275.1	99.81
10 μm cyclone	56,556.8	197.8	99.89
Total	112,503.8	649.9	99.82

[a] 9.26 dscm sampled.

[b] 29.22 dscm sampled.

[c] Normalized to equalize volume sampled.

Grab samples of the four bulk solid streams were taken at approximately 2-hour intervals during the inlet SASS run; samples were then composited.

SASS-train flue gas particulate catches were analyzed for ten species including Ra-226, U-234, U-235, U-238, Th-227, Th-228, Th-230, Th-232, Po-210, and Pb-210. Baghouse ash and spent bed solids were analyzed for nine radionuclides with Ra-226 levels estimated by assuming secular equilibrium. Coal and limestone feed streams were analyzed for the three uranium and four thorium isotopes with Ra-226, Po-210, and Pb-210 estimated assuming secular equilibrium. For the sake of comparison with the preceding utility radioassay data, we have elected to report analytical results for the six species of primary concern, i.e., the five uranium series species and Th-232.

RESULTS

Table G-3 summarizes results of radioanalysis of several Georgetown FBB samples. Activity is expressed as Ci/hr (dry weight). For radionuclides not quantified, secular equilibrium is assumed to exist and activity is assumed equal to that for the parent (here, U-228).

The baghouse ash mass flowrate is uncertain, as is the spent bed rate, but they are the best available estimates. Some of the total activities out (Pb-210 and Th-232) are greater than the total activities in and are attributed to radionuclide measurement inaccuracies and uncertainties in the solid mass flows. Projected radionuclide loadings at the stack (baghouse outlet) are low compared to the natural activity present in the coal and limestone. Since the baghouse was observed to operate at an estimated efficiency greater than 99 percent, the majority of radionuclides exiting the FBB are part of the baghouse ash. The activity of the baghouse ash was low; no isotope exceeded 1.5 pCi/g (dry weight). Levels of activity measured in spent bed material are similar to those reported for the Exxon Miniplant PFBC (see the following subsection of this Appendix) with the exception of Pb-210.

It is of interest to note the higher activity for all measured isotopes in the finest (1 m) fraction of combustor flue gas particles relative to the larger particles (3 m and 10 m). Studies have shown that there is a tendency for certain trace elements to be preferentially concentrated on the smaller fly ash particles following coal combustion. Enrichment factors were calculated considering the coal ash activity as the baseline and are provided in Table G-4.

TABLE G-3. FATE OF INDIVIDUAL RADIONUCLIDES WITHIN THE GEORGETOWN FBB

	Radionuclide flow rate, µCi/hr					
Sample description	U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
Coal feed	0.594	0.594	0.594	0.594	0.792	0.140
Sorbent feed	0.184	0.184	0.184	0.184	0.184	0.122
Total Activity In	0.778	0.778	0.778	0.778	0.976	0.262
Spent bed solids	0.068	0.068	0.012	1.02	0.068	0.047
Baghouse ash	0.518	0.454	0.518	0.907	0.454	0.421
Projected baghouse outlet loadings:	(Units of pCi/hr)					
1-3 µm particles	360	144	576	576	360	324
3-10 µm particles	324	288	360	576	324	324
10 µm particles	144	216	144	180	144	144
Total Activity Out	0.523	0.523	0.531	1.93	0.523	0.469
Percent Closure	63.5	67.3	68.3	248.3	53.6	178.4

TABLE G-4. ENRICHMENT FACTORS, GEORGETOWN FBB

Radionuclide	Enrichment factor
U-238	1.1
Ra-226	1.5
Po-210	1.6
Pb-210	1.8
Th-230	0.85
Th-232	4.5

EXXON MINIPLANT RADIOASSAY RESULTS[2]

PLANT DESCRIPTION

The Exxon Miniplant is an experimental pressurized fluidized-bed combustor (PFBC) and sorbent regeneration system with a coal firing capacity of 1.8 MW (6.3×10^6 Btu/hr). GCA conducted Level 1 and Level 2 environmental assessment sampling and analysis programs at the Miniplant in May and June 1979. Level 1 samples were obtained with the regenerator in operation and with an ESP as the final particle control device. Level 2 sampling was conducted when the unit was operating without regeneration and with a fabric filter for final particulate control. Table G-5 provides a summary of the Exxon Miniplant PFBC operating conditions.

SAMPLING AND ANALYSIS PERFORMED

Figure G-2 is a schematic of the Exxon Miniplant PFBC illustrating Level 1 sampling points; Figure G-3 shows the Level 2 sampling points. Several radioanalyses were performed on available Level 1 and 2 Exxon Miniplant samples by the NUS Radiological Laboratory.

RESULTS

Results of the radioanalysis of Exxon Miniplant Level 1 and Level 2 samples are summarized in Tables G-6 and G-7, respectively.

ESP hopper ash (Level 1) and Fabric Filter catch (Level 2) were not available in sufficient quantity to permit analysis for thorium. The data show higher radionuclide emission rates in the relatively fine particles collected by the final control devices (stream 1).

Data listed in Tables G-6 and G-7 illustrate the flow of individual radionuclides through the systems sampled. During the Level 1 program, spent combustion bed material was either regenerated or elutriated and collected by the cyclones so that the exit flow rate was zero. Total radionuclide input to the system is equal to that in the coal plus the sorbent. For radionuclides not quantified in the feed streams, secular equilibrium is assumed to exist and activity is assumed equal to that for the parent (U-238 or Th-232) which was measured. Stream flow rates for final particle control devices are assumed equal to the flow rate for undiluted flue gas multiplied by the average dust loading measured for that stream (i.e., the final control devices operate at high collection efficiencies).

The data in Table G-7 for level 2 show that most of the radionuclides leave the system in the spent combustor solids and the second cyclone catch. Level 1 data are similar except spent bed material leaves the system as part of the cyclone catch. Radionuclide emission rates following final particulate control were not quantified because of insufficient material for analysis. However, because of high particle capture efficiency, the emission rates would be approximately 1 to 2 orders of magnitude below the capture rate noted for the ESP during the Level 1 program or for the fabric filter during the Level 2 program.

TABLE G-5. SUMMARY OF EXXON MINIPLANT PFBC OPERATING CONDITIONS

	Combustor		Regenerator
Parameter	Level 1	Level 2	Level 1 only
Length of run (hours)	99	108	80.7
Pressure (kPa)	700	912	705
Average bed temp. (°C)	894	872	101-103 (reducing-oxidizing)
Expanded bed height (m)	3.1	1.74	1.85
Ca/S molar ratio	1.29	1.25	
Coal feed rate (kg/hr)	77	84.4	-
Sorbent feed rate (kg/hr)	5.44	10.60	-
Coal type	Champion coal	Champion coal	-
Coal higher heating value, kJ/kg	31,400	31,400	-
Sorbent type	Grove limestone	Pfizer dolomite	Grove limestone

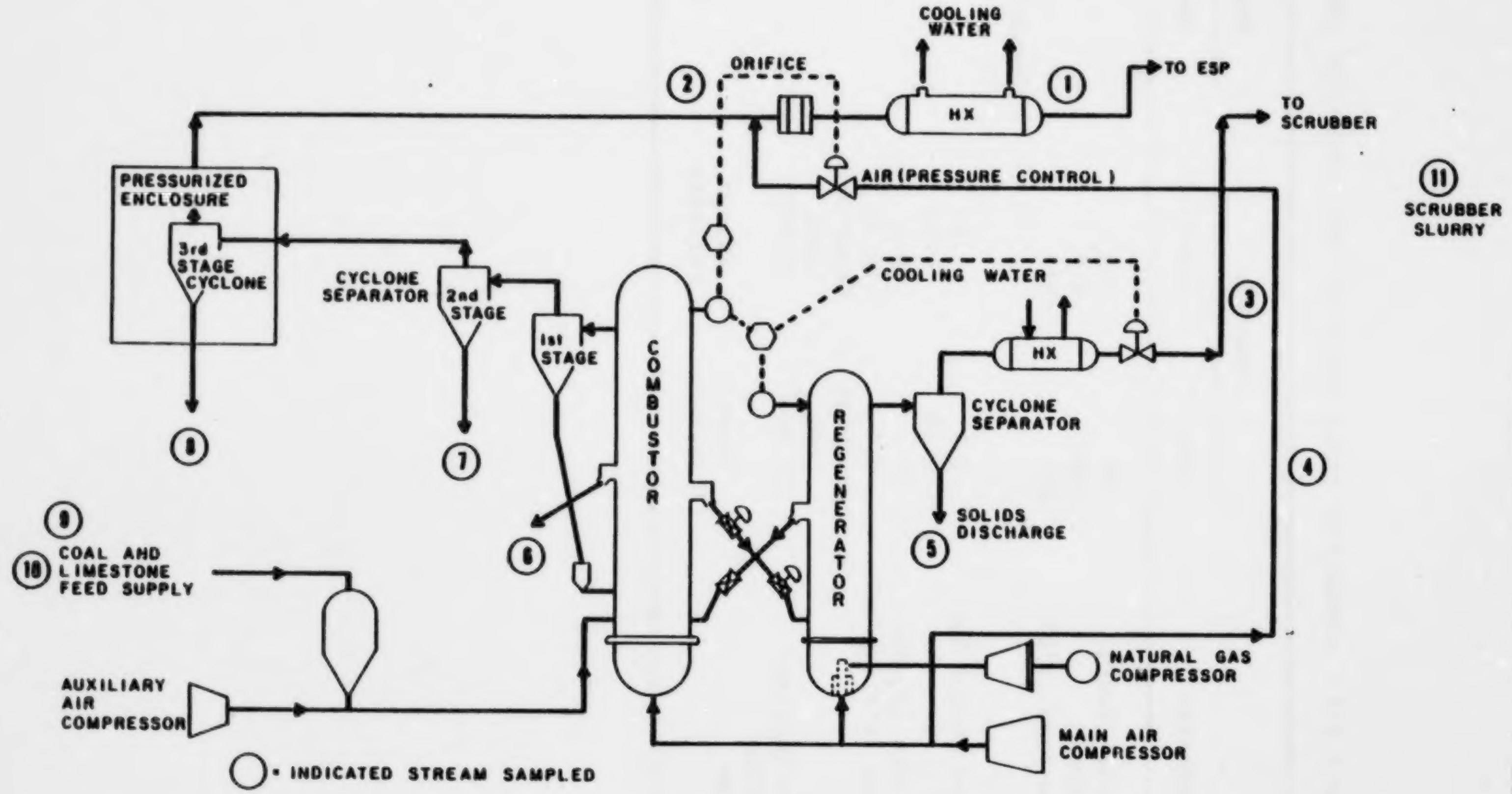

Figure G-2. The Exxon Miniplant - Level 1 sampling.

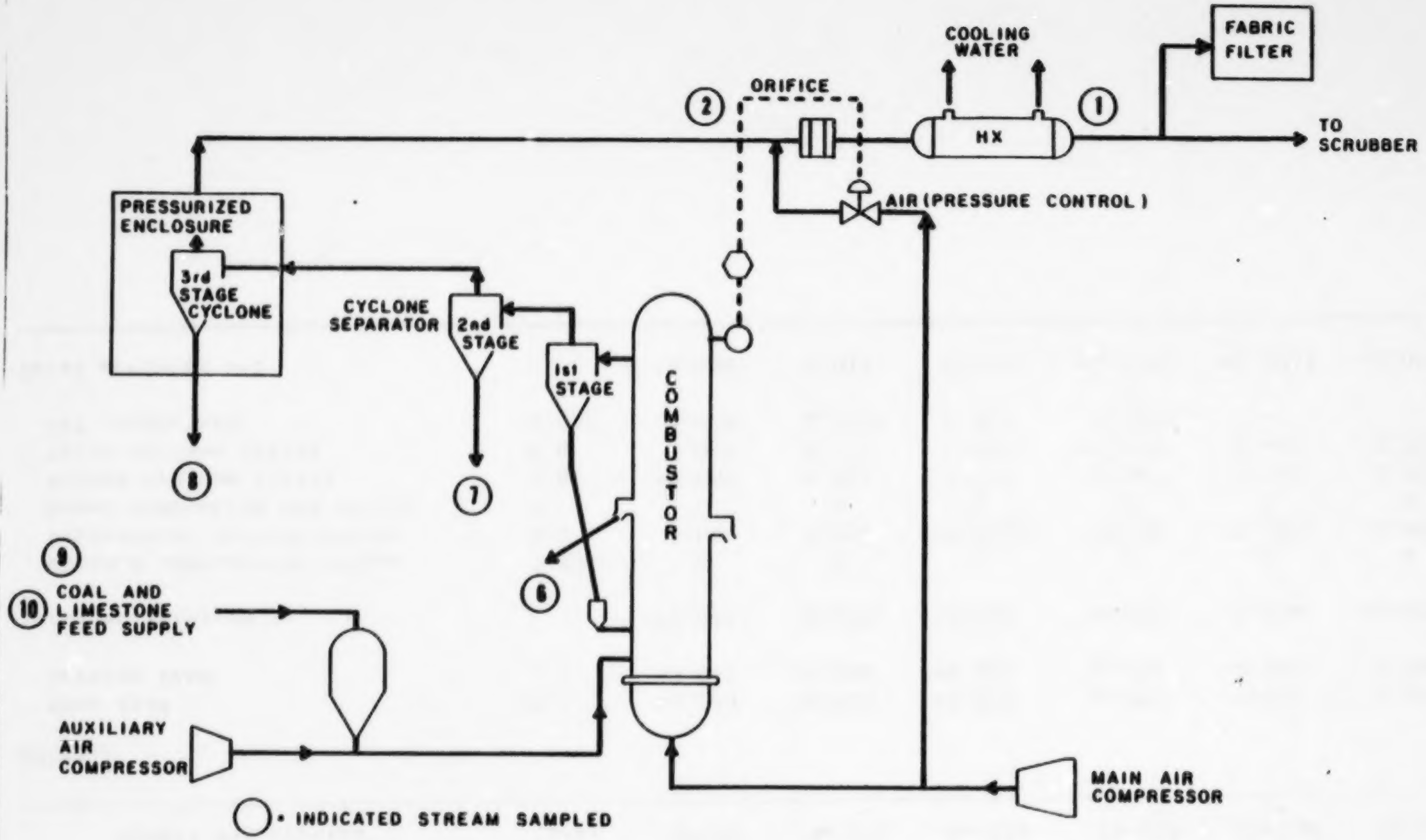

Figure G-3. The Exxon Miniplant - Level 2 sampling.

TABLE G-6. FATE OF INDIVIDUAL RADIONUCLIDES WITHIN THE EXXON MINIPLANT PFBC DURING LEVEL 1 TEST

Sample description	Solid flow rate (g/s)	Radionuclide flow rate, µCi/hr					
		U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
Level 1							
Coal feed	21.4	<0.023	<0.023	<0.023	<0.023	0.034	0.019
Sorbent feed	1.5	<0.002	<0.002	<0.002	<0.002	<0.002	<0.0007
Total activity in		<0.025	<0.025	<0.025	<0.025	<0.036	<0.0197
Cleaned regenerator offgas	0.0002	0	0	0	0	0	0
Regenerator cyclone solids	0.2	0.001	0.001	<0.00004	<0.006	<0.0004	<0.0004
Spent combustion bed solids	0	0	0	0	0	0	0
Second cyclone solids	1.6	<0.005	0.011	0.001	<0.06	<0.001	0.002
Third cyclone solids	0.4	0.002	0.007	0.0001	<0.013	0.002	0.002
ESP hopper ash	0.042	0.0007	0.0007	0.001	0.0002	-	-
Total activity out		<0.0087	0.0197	0.0214	<0.0792	<0.0034	<0.0044

TABLE G-7. FATE OF INDIVIDUAL RADIONUCLIDES WITHIN THE EXXON MINIPLANT PFBC DURING LEVEL 2 TEST

Sample description	Solid flow rate (g/s)	Radionuclide flow rate, μCi/hr					
		U-238	Ra-226	Po-210	Pb-210	Th-230	Th-232
Level 2							
Coal feed	23.4	0.012	0.012	0.012	0.012	0.045	0.027
Sorbent feed	2.9	0.005	0.005	0.005	0.005	0.006	<0.003
Total activity in		0.017	0.017	0.017	0.017	0.051	<0.03
Spent combustion bed solids	3.0	0.0072	0.010	0.001	<0.086	0.006	0.002
Second cyclone solids	2.1	0.018	0.015	0.0004	<0.038	0.035	0.003
Third cyclone solids	0.3	0.003	0.005	0.0004	<0.008	0.0004	0.001
Fabric filter catch	0.064	0.001	0.002	0.002	<0.001	-	-
Total activity out		0.0292	0.032	0.0038	<0.133	0.0414	0.006

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REFERENCES

1. Kindya, R. and C. Young. Radioisotopic Analysis of Samples from the Georgetown University Fluidized-Bed Boiler. Draft Final Report prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory under Contract No. 68-02-2693, Technical Directive No. 8, February 1981.

2. Kindya, R. and R. Hall. Radioassay of PFBC Miniplant Samples. Draft Final Report prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory under Contract No. 68-02-2693, Technical Directive No. 6, January 1980.